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COLLEGE OF EARTH AND MINERAL SCIENCES

FINAL TECHNICAL REPORT

SYNTHESIS OF REGIONAL CRUST AND UPPER-MANTLE STRUCTURE
FROM SEISMIC AND GRAVITY DATA

Grant No. NAG 5-77

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SECTION I

SUMMARY

SUMMARY

The principal objective of this investigation was to combine available
seismic and ground-based gravity data to infer the three-dimensional crust and
upper mantle structure in selected regions. This synthesis and interpretation
proceeded from large-scale average models suitable for early comparison with
high-altitude satellite potential field data to more detailed delineation of
structural boundaries and other variations that were significant in natural
resource assessment. While the study focussed primarily on seismic and
ground-based gravity data, other relevant information (e.g. magnetic field,
heat flow, Landsat imagery, geodetic leveling, natural resources maps) were
used to constrain the structures inferred and to assist in defining structural
domains and boundaries. The seismic data base that was used consisted of
regional refraction lines, limited reflection coverage, surface wave
dispersion, teleseismic P and S-wave delay times, anelastic absorption (Q),
and regional seismicity patterns. The gravity data base was all available
point gravity determinations for the areas considered.

Initially a synthesis and evaluation of previous seismic and gravity
investigations was made. These results were supplemented by further
interpretation of published data, analysis of other available seismic data,
and a systematic analysis of the irregularly sampled gravity field. The
interpretation made use of modern inversion methods, digital analysis
techniques, and empirical evidence on density-seismic velocity relationships
for crustal rocks. The final products consisted of a series of maps of the
crust and upper mantle structure along with the corresponding point-wise
digital representation of the structure for a grid of points covering the area
to facilitate quantitative comparisons with satellite potential field data and
other relevant observations.

The first area studied was the eastern United States (EUS) from the
Mississippi River to the Atlantic continental margin. A similar study of the
Australian continent was undertaken later in the investigation.

This grant is a continuation of Grant NS3 5276 and NCC5-19 that have
been reported upon previously. The appendix gives the details of the results
of this final portion of the investigation. They are summarized as follows:

MAJOR LINEAMENTS AND THE LAKE ERIE-MARYLAND CRUSTAL BLOCK

Analyses of regional gravity and magnetic patterns, LANDSAT images and
geological information have revealed two major lineaments crossing western
Pennsylvania and parts of surrounding states. These lineaments are inferred
to be expressions of fracture zones which penetrate deeply into the crust and
possibly the upper mantle. The extensions of the Tyrone-Mt. Union and the
Pittsburgh-Washington lineaments bound a distinct crustal block (Lake
Erie-Maryland block) over 100 km wide and probably more than 600 km in length.
Evidence exists for the lateral displacement of this block at least 60 km
northwestward during late Precambrian to Lower Ordovician time. Subsequent
movements have been mainly vertical with respect to neighboring blocks.

EVIDENCE FOR AN OFFSET CRUSTAL BLOCK IN THE SOUTHERN APPALACHIANS

A possible crustal block that passes through eastern Kentucky, proposed by a TVA study on tectonics in the southern Appalachians, was investigated using geophysical and geological information. The relation between the block and magnetic and gravity anomalies, seismicity, mineral occurrences, and deformation in the sedimentary section was examined, as well as the nature of the block and possible lateral offsets relative to the surrounding crust.

This study supports the existence of the block. The magnetic and gravity data show that the block is characterized by a low magnetic and gravity zone extending from southcentral Indiana to western Virginia. Numerous magnetic and gravity high and lows are truncated by this zone. It is suggested that the crustal block underwent about 45 km of relative offset to the southeast during pre-Keweenawan times. It is also suggested that since the Precambrian block has been reactivated during periods of tectonic stress, namely during the opening of the Proto-Atlantic , and the Taconic, Acadian, and Alleghenian orogenies. Movements during periods of reactivation are shown to be primarily minor vertical displacements.

The crustal block is shown to be, at present, relative.y aseismic, although the poor documentation of seismcity in the eastern United States makes this conclusion tentative. The boundaries of the block are shown to be deep crustal fractures, possibly extending to the upper mantle, along which mineral districts and occurrences are likely to exist. Also the block is shown to have influenced the deformation of the sedimentary cover. The detailed nature of the block is shown to be characterized by a deep crustal structure which results in the low magentic zone associated with the block. The nature of the structure itself is unknown due to a lack of data from seismic reflection and refraction surveys.

IMPLICATIONS OF REGIONAL GRAVITY AND MAGNETIC DATA FOR
STRUCTURE BENEATH WESTERN PENNSYLVANIA

Regional gravity and magnetic data were used in this study to identify major crustal structures beneath western Pennsylvania and parts of surrounding states. A two-dimensional gravity model was constructed using available geophysical and geological data to constrain an assumed crustal structure consisting of three constant density layers. The major gravity anomalies were primarily attributed to northeast-trending topographic highs and lows along the top of the basement. Two basement structures, whose full extent was previously unrecognized in the geological literature, were identified. A deep sedimentary basin near Beaver Falls, Pennsylvania, appears to have a maximum depth of about 8.5 km. A smaller basin is developed near Greensburg, Pennsylvania.

The gravity low over Martinsburg, West Virginia, was also modeled as a prominent sedimentary basin, a portion of the Appalachian basin. A small, but distinct, gravity anomaly near Chaneysville, Pennsylvania, was attributed to tectonically thickened sediments beneath the Appalachian Front. The broad gravity high centered over Somerset, Pennsylvania could not be explained by sedimentary/basement sources alone. A slight decrease in crustal thickness is believed to be associated with this anomaly.

The Greensburg low, or alternatively, the Beaver Falls low, is believed to be a probable site for the northeast extension of the Rome trough. The basement features modeled in this study could reflect major growth faults or an unresolved ser es of faults in an extensive fault zone. A correlation between basement highs and sedimentary structures was noted near the Applachian and Intraplateau structural fronts. This association may indicate some involvement of basement rocks in the deformation of overlying sedimentary rocks.

A second set of structures was identified by analysis of regional gravity and magnetic patterns, and geological information. Evidence is presented to propose the extension and redefinition of major lineaments crossing the study area. The Tyrone-Mt. Union and newly defined Pittsburgh-Washington lineaments enclose a distinct crustal block over 100 km wide and probably greater than 600 km in length with the thickness of the crust. This crustal block, named the Lake Erie-Maryland block, has been displaced, in one or more episodes, northwestward at least 50-60 km, probably during Upper Cambrian or Lower Ordovician time, with respect to the surrounding crust. The Everett lineament appears to be unrelated to the lineaments associated with the Lake Erie-Maryland block. A possible connection between the Lake Erie-Maryland crustal block and plate tectonic models is also described. The bounding lineaments are likely to mark transform faults or possibly fracture zones developed as part of a triple junction.

SECTION II

MAJOR LINEAMENTS AND THE LAKE ERIE-MARYLAND CRUSTAL BLOCK

MAJOR LINEAMENTS AND THE LAKE ERIE-MARYLAND CRUSTAL BLOCK

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Abstract. Analyses of regional gravity and magnetic patterns,
LANDSAT images and geological information have revealed two major line-
aments crossing western Pennsylvania and parts of surrounding states.
These lineaments are inferred to be expressions of fracture zones which
penetrate deeply into the crust and possibly the upper mantle. The ex-
tensions of the Tyrone-Mt. Union and the Pittsburgh-Washington line-
aments bound a distinct crustal block (Lake Erie-Maryland block) over
100 km wide and probably more than 600 km in length. Evidence exists
for the lateral displacement of this block at least 60 km northwestward
during late Precambrian to Lower Ordovician time. Subsequent movements
have been mainly vertical with respect to neighboring blocks.

INTRODUCTION

Recent studies [e.g., Sykes, 1978] have shown that the continental
lithosphere in many regions is not rigid and continuous, as envisioned
in simple plate tectonic models. This is particularly true along con-
tinental margins where repeated episodes of continental collision and
continental rifting have produced fault and fracture zones, failed rift
structures, continental suture zones, and other tectonic boundaries.
These tectonic boundaries divide the lithosphere into fragments. This
type of block tectonic structure appears to characterize the structural
fabric of the eastern United States.

In Pennsylvania and surrounding states, in particular, available geo-
physical and geological data suggest the presence of a northwest-
trending rectangular crustal block, over 100 km wide and possibly
greater than 600 km in length, which is at least as thick as the crust.
This block, called the Lake Erie-Maryland block, has been displaced at
least 50-60 km to the northwest with respect to the surrounding crust,
in one or more episodes, along deep fracture zones, probably during late
Precambrian to Lower Ordovician time.

The Lake Erie-Maryland block and similar structures identified in New
York State [Diment et al., 1980] may reflect a pervasive feature of
'passive' continental margins. Recognition of these structures else-
where could be useful in the analysis of regional seismicity and seismic
risk, since deep fracture zones are potentially active fault zones. The
independent motion of crustal blocks could also play an important role
in vertical tectonics and sedimentary basin evolution. Knowledge of
lateral displacements of individual blocks, together with the timing of
such movements, is necessary in order to develop an exploration strategy
for deep oil and gas deposits. The evidence for such a block in
Pennsylvania and surrounding states is presented in this paper.

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THE BOUNDING LINEAMENTS OF THE LAKE ERIE-MARYLAND CRUSTAL BLOCK

Two deep crustal fractures bounding the Lake Erie-Maryland (LEM)
block are suggested by a variety of geophysical and geological data sum-
marized in Figure 1. A complete synthesis can be found in the work of
Chaffin [1981]. In central Pennsylvania the northern fracture is marked
by the well-known Tyrone-Mt. Union (TMU) lineament [Gold et al., 1973].
This lineament, visible on LANDSAT images, is characterized by the
alignment of surficial structures in a 0.5- to 2.0-km-wide zone striking
across regional geologic trends in the Valley and Ridge province for a
distance of approximately 100 km. This zone is also characterized by
increased fracture density and geometrically related faulting and
jointing [Canich and Gold, 1977], Pb-Zn and Cu mineralization [Smith et
al., 1971], plunging anticlines [Kowalik, 1975], and termination of
third- and fourth-order folds and faults [Canich and Gold, 1977].

Canich and Gold [1977] concluded that the evidence in the Valley and
Ridge province indicates that the TMU lineament is produced by a buried
fracture zone whose surface expression is controlled by currently active
Precambrian structures. Base mineralization along the lineament [Smith
et al., 1971] supports a projection of the surficial features described
above to the Precambrian basement and possibly to greater depths.

Another well-expressed lineament (T in Figure 1) seen on LANDSAT
images, greater than 40 km in length, crosses Crawford County, Penn-
sylvania, beginning near Titusville [Kowalik, 1975] and is on strike
with the TMU lineament. Increased fracture permeability and enhanced
vertical migration of hydrocarbons associated with the lineament, and
stratigraphic data suggest that it is a deep fracture zone, possibly
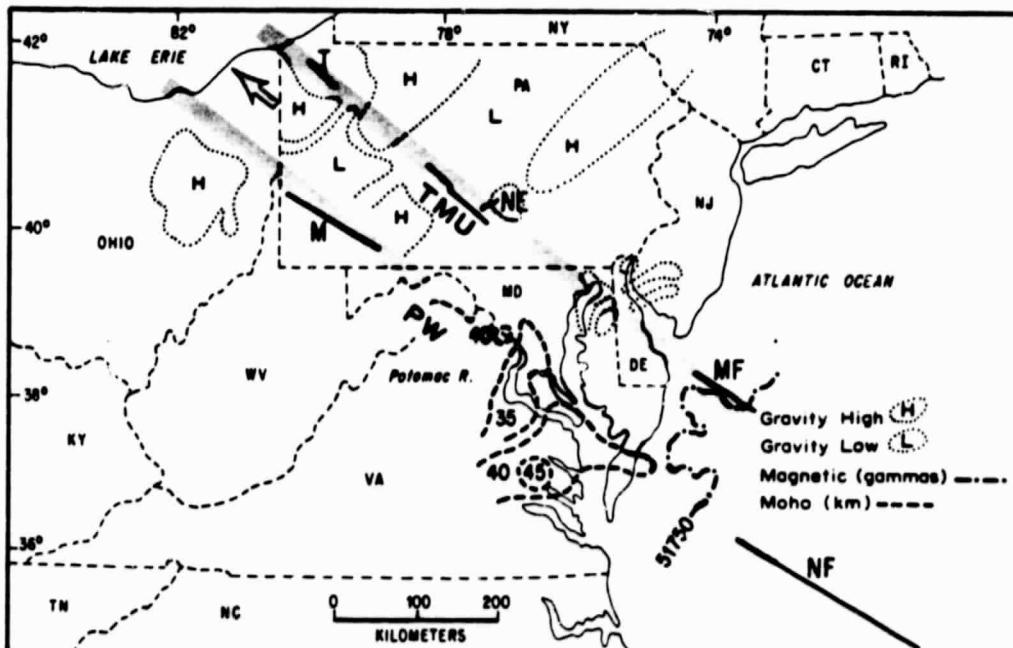
Fig. 1. Summary of evidence suggesting possible extension of the
Tyrone-Mt. Union (TMU) lineament and defining the Pittsburgh-Washington
(PW) lineament. Arrow indicates relative direction of motion of Lake
Erie-Maryland crustal block. Letters designate features discussed in
the text.
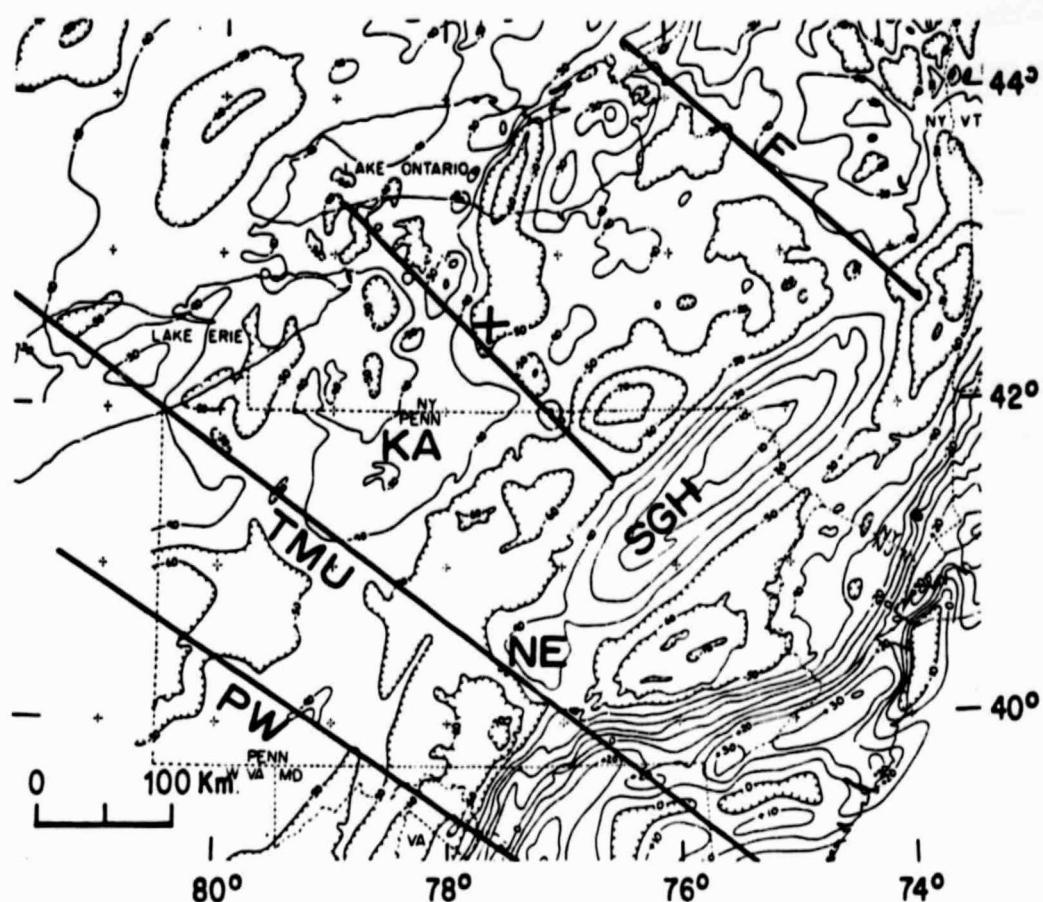
Fig. 2. Simple Bouguer anomaly map (contour interval = 10 mgal) after
Diment et al. [1980]. Heavy lines are the Tyrone-Mt. union (TMU) and
Pittsburgh-Washington (PW) crustal lineaments. The Kane (KA), Scranton
(SGH), and Newport (NE) gravity highs are labeled. X and F are line-
aments discussed by Diment et al. [1980].

preserving an up-to-the-north vertical displacement, which is not thick-
skinned in origin [Rodgers, 1981].

Major gravity anomalies (Figure 2) in the Appalachian Plateau of
western Pennsylvania appear to be interrupted along a northwest-trending
zone which is essentially on strike with the TMU and Crawford County
lineaments (approximate outlines of these gravity highs (H) and lows (L)
are shown in Figure 1). Terminations, interruptions, and anomalous
trends are observed in magnetic data along the same trend (Figure 3).
These observations indicate that a fracture zone is associated with the
TMU lineament, which is a continuous structure extending to the north-
west at least as far as Lake Erie.

This zone also appears to extend to the southeast as suggested by the
termination of the Newport gravity and magnetic high (NE), which is on
the same trend (Figure 1). A map of the Precambrian basement in this
area, inferred from stratigraphic projections [Chen, 1977], shows the
20,000-foot contour is disrupted in this zone; this implies that base-
ment rocks are disturbed in the fracture zone.

There is additional evidence which suggests that this fracture zone

or possibly a related structure persists in the crust of coastal states
and extends offshore. Saddle-like and straight-edged magnetic anomalies
[Zietz et al., 1980] characterize a zone approximately coincident with
the southern shore of the Delaware Bay. Gravity anomalies are inter-
rupted in the same region (Figure 1). Sheridan [1974] has identified a
continental margin fault which is on strike with the landward lineament
zone (MF in Figure 1). This fault coincides with a topographic high
that divides the Baltimore Canyon into two distinct basins. A rec-
tangular-shaped magnetic high [Klitgord and Behrendt, 1977], with a mag-
nitude of about 200 gammas, is abruptly terminated or offset in the same
area (Figure 1).

The observations discussed above suggest that the fracture zone
associated with the TMU lineament extends from Lake Erie to beyond the
Atlantic coastline, a distance in excess of 600 km. The lineament zone
is linear or concave toward the north in shape (possibly part of a great
circle path), and its length, persistence through a variety of geologic
terrains, and geophysical expressions indicate a fracture zone pene-
trating deeply into the crust, perhaps into the upper mantle.

The fracture zone defining the southern boundary of the LEM block,
the Pittsburgh-Washington lineament, has an approximate parallel trend
and is strongly expressed in southwestern Pennsylvania by a steep mag-
netic gradient (>500 gammas relief) south of Pittsburgh (M in Figure 1;
PW in Figure 3). Recently acquired detailed gravity data show that
gravity anomalies are disrupted and possibly offset along the same zone.
Some suggestion of this can be seen in Figure 2.

Additional geological evidence for the existence of the southern
fracture zone may be cited. A zone of structural discontinuity, along
which folds are interrupted or terminated, has been mapped by Wagner and
Lytle [1976] in the Appalachian Plateau of western Pennsylvania parallel
to the lineament. Some folds are also developed parallel to this zone.
Thrusts in the Martinsburg shale terminate or change strike south of the
lineament in the same area, while the Martinsburg is not thrusted to the
north [Parrish, 1978]. This change of structural style may indicate
semi-independent movement of sedimentary blocks along the zone. The
discontinuity apparently controls the distribution of some of the Upper
Devonian oil and gas fields [Abriel, 1978].

The southeastward continuation of the southern fracture zone is in-
dicated by surficial and geophysical information. A linear segment of
the Potomac River Valley (part of Hobbs' [1904] Potomac lineament)
crosses the geological grain and suggests the subsurface fracture zone
forms part of the Maryland border with Virginia (Figure 1). A plot of
historical seismicity [Bollinger, 1973] includes two concentrations of
epicenters in northern Virginia and eastern West Virginia along the pro-
posed fracture zone. Magnetic patterns in the same area [Zietz et al.,
1980] include truncated anomalies and indications of magnetic trends
cutting across the regional grain. Gravity maps which cover this area
[e.g., Woollard and Joesting, 1964] are constructed from sparse data,
but there is a suggestion of the disturbance of a few anomalies here.

Further southeast, the lineament is proposed to extend beneath the
Potomac or Putuxent River inlet of the Chesapeake Bay. A map of crustal
thickness prepared by James et al. [1968] shows northwest-trending Moho
structures south of the lineament in this area (Moho depths are shown in
Figure 1). Northwest-trending gravity anomalies suggest the fracture
zone continues beneath the Atlantic shoreline of Northampton County,
Virginia. The lineament is defined offshore in the Atlantic by the
southern flank of the magnetic high [Klitgord and Behrendt, 1977] men-
tioned earlier in connection with the TMU lineament (Figure 1). The
Norfolk fracture zone (NF in Figure 1) inferred by Sheridan [1974] may
represent an extension of the lineament more than 150 km offshore.

The northwest extension of this fracture zone may pass along the
linear northwest flank of the prominent gravity high [Ohio Division of

Geologic Survey, 1956] centered over Wayne County, Ohio (Figure 1). A
concentration of historical earthquake epicenters [York and Oliver,
1976] on this trend may extend it to the shore of Lake Erie.

THE LAKE ERIE-MARYLAND CRUSTAL BLOCK

The two crustal fractures described above define the boundaries of
the Lake Erie-Maryland (LEM) crustal block, a northwest-trending feature
over 100 km wide and at least 600 km in length. Several lines of
evidence indicate that the LEM block may be an independent crustal unit.
The great length, persistence through different geological terrains,
subparallel orientation, and strong geophysical expression of the linear
features described above suggest that the fracture zones are deep,
possibly penetrating the entire crust. Further, a plot of seismic delay
times shown by Herrin [1969], although based on scant data, does include
positive delay times in a zone roughly coinciding with the LEM block.
Herrin [1969] suggested that these delay times are developed along the
upper portions of the ray paths from which the map was constructed.
Possibly these data reflect a region of thickened crust or vertical
offset along the fractures. The block appears to be aseismic relative
to the surrounding blocks inferred by Diment et al. [1980] and Chaffin
[1981].

Additional evidence may be cited. The conspicuous magnetic gradient
marking the New York-Alabama magnetic lineament [King and Zietz, 1978]
is disrupted, possibly offset or absent, between the proposed fracture
zones (NYA in Figure 3). In addition, the offshore rectangular magnetic
high described earlier (Figure 1) suggests a blocklike structure between
the offshore extensions of the lineaments. Parrish [1978] has reviewed
the lineaments mapped in western Pennsylvania within the LEM block.
Most appear to be confined to the sedimentary section and upper
basement, since they are not strongly reflected in gravity or magnetic
data. No indication of major displacements along these fractures
between the TMU and Pittsburgh-Washington lineaments is apparent. Thus
the structures preserved within the LEM block seem to be relatively
undisturbed within the block but interrupted or terminated along the
deep crustal fractures beneath the bounding lineaments.

While it is not yet possible to present a complete tectonic history
of the LEM block, gravity, magnetic, and geological data suggest major
crustal displacements have occurred along the bounding fracture zones.
Davis [1980] reported that a comparison of detailed northwest-trending
magnetic profiles about 100 km apart on opposite sides of the TMU
lineament (Figure 3) indicated about 60 km of right-lateral displacement
is preserved along the lineament. A realignment of the magnetic
profiles at their respective maxima (shaded in Figure 3) is shown in
Figure 4. Southeast of the maxima the two profiles are quite similar in
character, indicating that at one time the basements were probably
aligned. Northwest of the maximum on the southern profile, the end of
available detailed data is encountered at the Ohio border. The shore of
Lake Erie is located some 19 km northwest of the beginning of the
northern profile, and data there are lacking. It is difficult,
therefore, to assess the similarity of the two profiles in the region
northwest of their respective maxima.

This offset is also suggested by a comparison of Upper Cambrian
growth faults [Wagner, 1976] mapped on opposite sides of the fracture
zone (Figure 3). The correspondence between the offsets in the axis of
the magnetic high as discussed above and Wagner's [1976] late Cambrian
growth faults across the TMU lineament is remarkable (Figure 4).
Similarly, Muller et al. [1980] suggested that 60 km of right-lateral
offset along the TMU lineament is indicated by the disruption of the
magnetic gradient marking the New York-Alabama lineament as well as the
displacement of the northeastward-trending magnetic high. The
configuration of the offshore magnetic high described earlier (Figure 1)
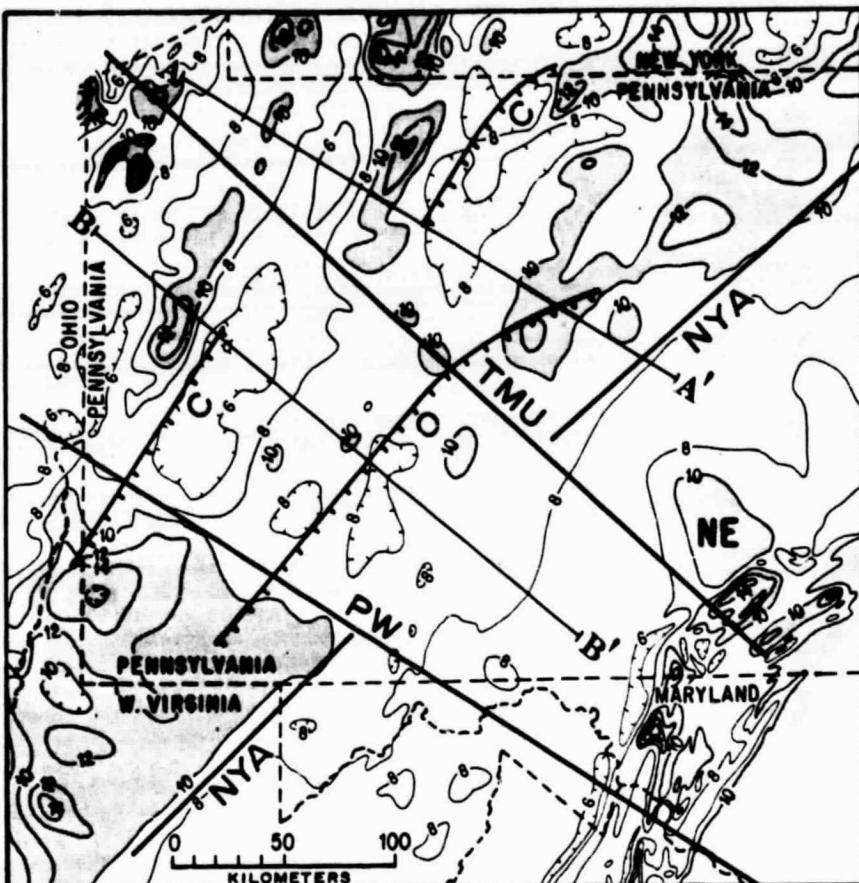
Fig. 3. Aeromagnetic map of western Pennsylvania [after Zietz and
Gilbert, 1981].   Contour values are in hundreds of gammas.   The shaded
areas are the magnetic highs referred to in the text.   The Tyrone-Mt.
Union (TMU), Pittsburgh-Washington (PW), and New York-Alabama (NYA)
lineaments are shown.   Wagner's [1976] Upper Cambrian (C) and Lower
Ordovician (O) growth faults are indicated by the hachured lines.   The
dashed lines are along the magnetic profiles shown in Figure 4.

also suggests about 60 km of right-lateral offset along the TMU
lineament.   A comparison of regional gravity patterns north and south
of the lineament (Figure 2) indicate crustal offsets in excess of 100 km
may have occurred, resulting in the present-day offset of the major
gravity highs and lows (marked by H's and L's in Figure 1).   Such
displacements could reflect an earlier tectonic episode than that which
produced the magnetic anomaly displacement.

Evidence for offset along the southern boundary of the block is
weaker.   Deflected isogals within major gravity anomalies in
southwestern Pennsylvania suggest about 50 km of left-lateral offset
along the fracture zone.   In addition, Sykes [1978] reported a 50 km
left-lateral offset of the magnetic high bounding the offshore extension
of the lineament (Figure 1).

Wagner's [1976] growth faults shown in Figure 3 enable some bound to
be placed on the possible timing of movement of the LEM block.   Late
Cambrian growth faults are offset, while the early Ordovician growth
fault is not; movement then occurred within that intervening time or
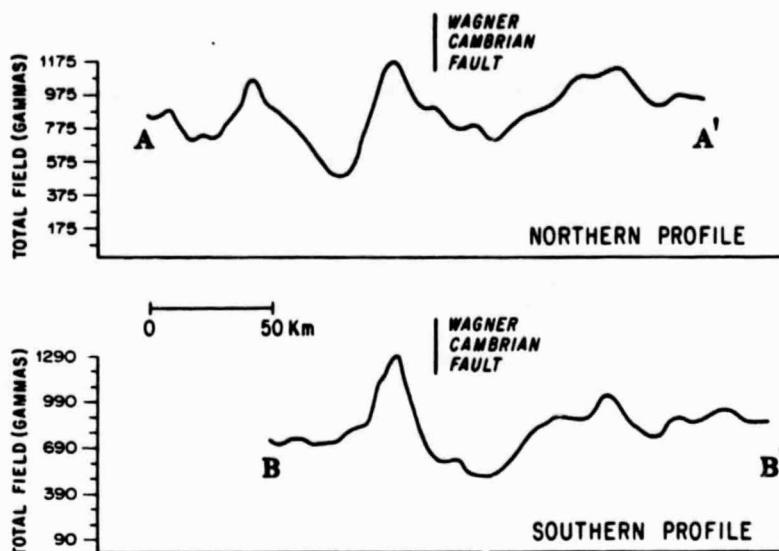
Fig. 4.   Northern and southern magnetic profiles (located in Figure 3)
shifted 60 km to align the field maxima. Wagner's [1976] late Cambrian
growth faults are also brought into alignment by this shift.

earlier. Parrish [1978] summarized the evidence for vertical uplift of
the area north of the TMU lineament marked by the Kane gravity high (KA
in Figure 2). This neighboring area is characterized by the absence of
the Devonian Oriskany sandstone. Williams and Bragonier [1974] showed
that this area was uplifted during Mississippian and Pennsylvanian
times. Rodgers [1981] presents evidence for vertical uplift from Lower
Devonian through Lower Pennsylvanian time. Therefore crustal block
movement along the northern boundary of the LEM crustal block has
changed from dominantly lateral displacement accumulating an offset of
at least 60 km (from late Precambrian to Lower Ordovician time) to
dominantly vertical displacements resulting in relative uplift of the
area to the north of the LEM block during the remainder of the
Paleozoic.

TECTONIC MODEL

    The fracture zones suggested here define major tectonic boundaries
which are compatible with plate tectonic models for the eastern United
States. Sykes [1978] proposed a tectonic model for intraplate regions
including the Appalachian fold belt. He suggested a genetic
relationship between 'preexisting zones of weakness' and major transform
faults which were active during the opening of adjacent oceans. The
possible association of deep continental fractures with oceanic
transform faults, described earlier, and the subparallel orientation of
the lineaments with respect to the direction of Atlantic seafloor
spreading suggests that Sykes' model may apply to these fractures.
    The origin of the fractures remains uncertain. Thomas [1977]
proposed a sequence of rifts and transform faults defining the ancient
Atlantic continental margin to explain the present geometry of the
Appalachian Mountain chain. Subsequent continental collision(s)
produced fold belts which conformed to the continental margin. Thomas'
[1977, Figure 1] reconstruction suggests transform faults which are
nearly on strike with the two fracture zones proposed here. Perhaps the
lineaments and the LEM block formed when a microcontinent, suggested by
Thomas' reconstruction, was trapped between colliding continents,

forcing a northwestward displacement of the LEM crustal block. It is
also possible that the crustal fractures associated with the lineaments
developed as transform faults in the lower crust during Precambrian
seafloor spreading. Subsequent deposition of the overlying
eugeosyncline [Dietz and Holden, 1966] and later reactivation of the
transform faults produced the fracture zone now observed in the basement
and sedimentary cover.

A final suggestion for an offset mechanism involves the Scranton
gravity high (SGH in Figure 2). The Scranton gravity high probably
reflects a large dense block of mafic material penetrating much of the
crust [Hawman, 1980] and appears to be terminated to the southwest near
the TMU lineament. Perhaps this block acted as a buttress to
deformation during Paleozoic continental collision(s). As the
continental margin deformed, this buttress north of the TMU lineament
may have inhibited its displacement, resulting in movement of the crust
south of the lineament further northwestward along a newly created or
preexisting fracture zone. Northwestward movement of the order of 40 km
of the LEM block and the block southwest of the Pittsburgh-Washington
lineament, moving as a single unit, may have occurred following the
formation of the major depositional basins in this region during the
late Precambrian. If so, it was followed by an additional northwestward
displacement of only the LEM block of 60 km prior to the early
Ordovician. Such a scenario would result in the apparent total offset
of 100 km along the TMU lineament, marked by the offset in major gravity
anomalies, and 60 km offset along the PW lineament evidenced by offsets
in the magnetic anomalies across this boundary. These ancient zones of
weakness appear to have persisted throughout geologic time. Subsequent
movements have been mainly vertical with respect to neighboring blocks.

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SECTION III

IMPLICATIONS OF REGIONAL GRAVITY AND MAGNETIC DATA FOR STRUCTURE
BENEATH WESTERN PENNSYLVANIA

The Pennsylvania State University

The Graduate School

Department of Geosciences

Implications of Regional

Gravity and Magnetic Data for

Structure Beneath Western Pennsylvania

A Thesis in

Geophysics

by

David Leland Chaffin

Submitted in Partial Fulfillment
of the Requirements
for the Degree of


Master of Science

May 1981

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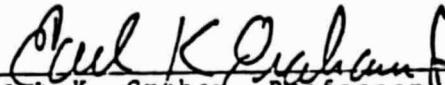
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23 April 81   _Randolph J. Martin III_
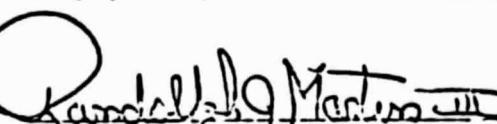
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ABSTRACT

Regional gravity and magnetic data were used in this study to identify major crustal structures beneath western Pennsylvania and parts of surrounding states. A two-dimensional gravity model was constructed using available geophysical and geological data to constrain an assumed crustal structure consisting of three constant density layers. The major gravity anomalies were primarily attributed to northeast-trending topographic highs and lows along the top of the basement. Two basement structures, whose full extent was previously unrecognized in the geological literature, were identified. A deep sedimentary basin near Beaver Falls, Pennsylvania, appears to have a maximum depth of about 8.5 km. A smaller basin is developed near Greensburg, Pennsylvania.

The gravity low over Martinsburg, West Virginia, was also modeled as a prominent sedimentary basin, a portion of the Appalachian basin. A small, but distinct, gravity anomaly near Chaneysville, Pennsylvania, was attributed to tectonically thickened sediments beneath the Appalachian Front. The broad gravity high centered over Somerset, Pennsylvania could not be explained by sedimentary/basement sources alone. A slight decrease in crustal thickness is believed to be associated with this anomaly.

The Greensburg low, or alternatively, the Beaver Falls low, is believed to be a probable site for the northeast

extension of the Rome trough. The basement features modeled
in this study could reflect major growth faults or an
unresolved series of faults in an extensive fault zone. A
correlation between basement highs and sedimentary
structures was noted near the Appalachian and Intraplateau
structural fronts. This association may indicate some
involvement of basement rocks in the deformation of
overlying sedimentary rocks.

A second set of structures was identified by analysis
of regional gravity and magnetic patterns, and geological
information. Evidence is presented to propose the extension
and redefinition of major lineaments crossing the study
area. The Tyrone-Mt. Union and newly defined Pittsburgh-
Washington lineaments enclose a distinct crustal block over
100 km wide and probably greater than 600 km in length with
the thickness of the crust. This crustal block, named the
Lake Erie-Maryland block, has been displaced, in one or more
episodes, northwestward at least 50-60 km, probably during
Upper Cambrian or Lower Ordovician time, with respect to the
surrounding crust. The Everett lineament appears to be
unrelated to the lineaments associated with the Lake Erie-
Maryland block. A possible connection between the Lake
Erie-Maryland crustal block and plate tectonic models is
also described. The bounding lineaments are likely to mark
transform faults or possibly fracture zones developed as
part of a triple junction.

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CHAPTER I

INTRODUCTION

The expanding domestic search for oil and gas has
renewed interest in the virtually unexplored, deep
sedimentary sections and basement complex of the Appalachian
Plateau and Valley and Ridge provinces. Presently, few deep
wells have been drilled in western Pennsylvania. Here,
geophysical methods must be used to examine subsurface
structure. Detailed seismic reflection data have been
collected in some areas for the oil industry but,
unfortunately, are not available and rarely show basement
reflections. Gravity and magnetic data, however, are
available over much of the area. These data are utilized in
this study to identify major crustal structures.

In addition to oil and gas recovery, another practical
benefit of subsurface exploration could be the recognition
of potentially active fault zones. The identification of
basement structures may also help to answer fundamental
questions concerning the evolution of the Appalachian
mountain system. In particular, geologists have long
debated the role of the basement in the deformation of the
overlying sedimentary cover. An association of structures
developed in the Paleozoic strata with basement structures
could indicate an influential role. In more general
investigations, uncertainties concerning the structure and
tectonics of the intraplate regions, including the

Appalachian foldbelt, have received increased attention.

Various studies have clearly demonstrated the presence of northeast-trending sedimentary deposition axes and associated fault structures within western Pennsylvania. In addition, at least two major northwest-trending lineaments, the Tyrone-Mt. Union and Everett-Bedford lineaments, have been documented. These lineaments are believed to mark deep crustal fractures. The purpose of this study is to extend these results using gravity and magnetic data. Specifically, evidence will be presented that: 1) identifies structures producing major gravity anomalies over western Pennsylvania, 2) locates possible extensions of the Rome trough of eastern Kentucky and West Virginia, 3) redefines and/or extends the two major lineaments, 4) indicates lateral movements along these lineaments, and 5) suggests the nature of the crustal block defined by these lineaments.

Chapter II provides background information for subsequent chapters. It consists of a discussion of data utilized in this study, previously identified structures and the general geology of the primary study area. Chapter III presents a model of crustal structure prepared for the purpose of locating features reported in previous work and identifying yet unrecognized structures. Chapter IV is a presentation of evidence for the existence of a crustal block passing through western Pennsylvania. The final chapter is a summary of results and conclusions.

CHAPTER II

SOURCES OF DATA AND PREVIOUS WORK

Sources of Geophysical Data

The gravity and magnetic data used in this study were collected from a number of sources. The primary source of gravity data is the Preliminary Bouguer Gravity Map of Pennsylvania compiled by Lavin (1980). About 1500 additional stations were occupied by the author during the summer months of 1979. These data sets were combined to provide improved coverage over western Pennsylvania. The simple Bouguer gravity values are accurate to within 1 mgal or better. Typical station spacing is about 5 km although station density is variable over the study area. The spacing is several times greater outside the borders of Pennsylvania. The composite data set was interpolated on to a square grid and computer contoured at a 2-mgal interval, using computer programs on file with the Geophysics Department. The resulting map is shown in Figure 1.

Generally, these gravity data are not terrain corrected. Such corrections would be useful in the rugged topography of central Pennsylvania where some corrections exceed 3 mgals (Muller, 1980). Over similar terrain in West Viginia, Kulander and Dean (1978) found typical corrections of about :.8 mgals. Overall, 23% of their corrections exceeded 3 mgals. Corrections of this magnitude will not significantly alter the results of a regional study and are

Figure 1. Bouguer gravity map of central and western
Pennsylvania (modified from Lavin, 1980).
Contour interval is 2 mgals. Distances along
line WE in km. See text for other symbol
explanations.
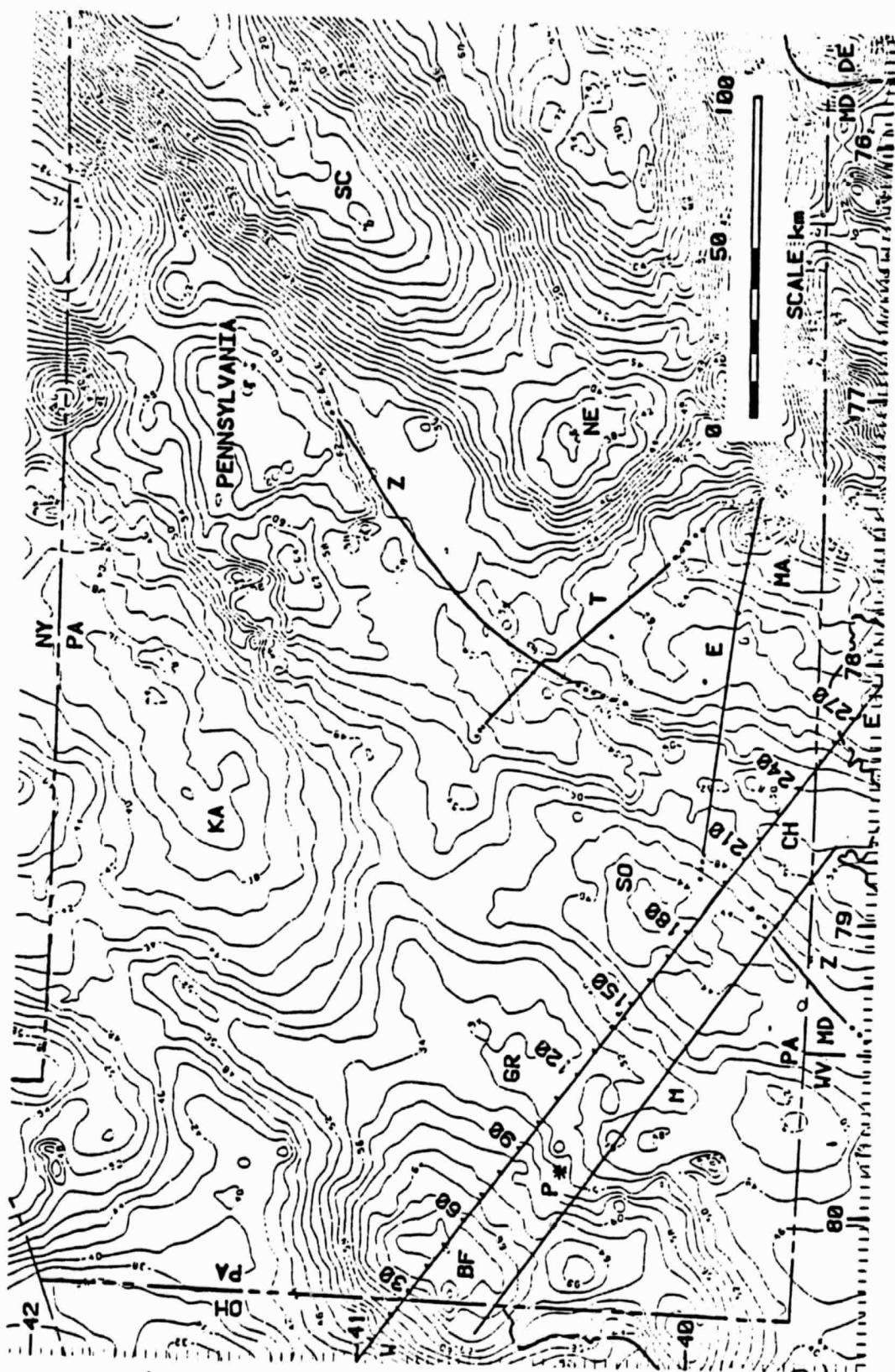
therefore not included here. Additional gravity data were
obtained from surveys conducted in surrounding states and
are referenced later where appropriate.

Magnetic data, used for quantitative analysis in the
study area, were taken from the Aeromagnetic Map of
Pennsylvania (U. S. Geol. Survey, 1978) and the aeromagnetic
map prepared by Popenoe et al. (1964). These maps display
the total magnetic field intensity measured at an adjusted
flight elevation of 1000 feet and contoured at a 10-gamma
interval. The aeromagnetic map provided by Zietz et al.
(1980), contoured at a 50-gamma contour interval, was used
for qualitative analysis of regional magnetic patterns
(Figure 2). Other magnetic maps were used for qualitative
analysis of surrounding areas and are referenced in later
chapters.

Location and General Geology of Study Area

The primary study area is the southwest quadrant of
nnsylvania and parts of adjacent states (Figure 3). Part
of this study also involves a southeastward extension into
other Atlantic states and portions of the continental shelf.
The primary study area falls within the Folded Central
Appalachian Mountains (Root, 1973). This classic terrain
consists of narrow elongate belts, distinguished by their
rock types and structures, oriented subparallel to the
eastern U.S. coastline. These belts overlie an oblong
asymmetrical basin whose long axis extends from the Canadian

Figure 2. Aeromagnetic map of Pennsylvania (after Zietz
et al., 1980). Contour interval is 50 gammas.
Dark areas mark magnetic highs. See text for
other symbol explanations.
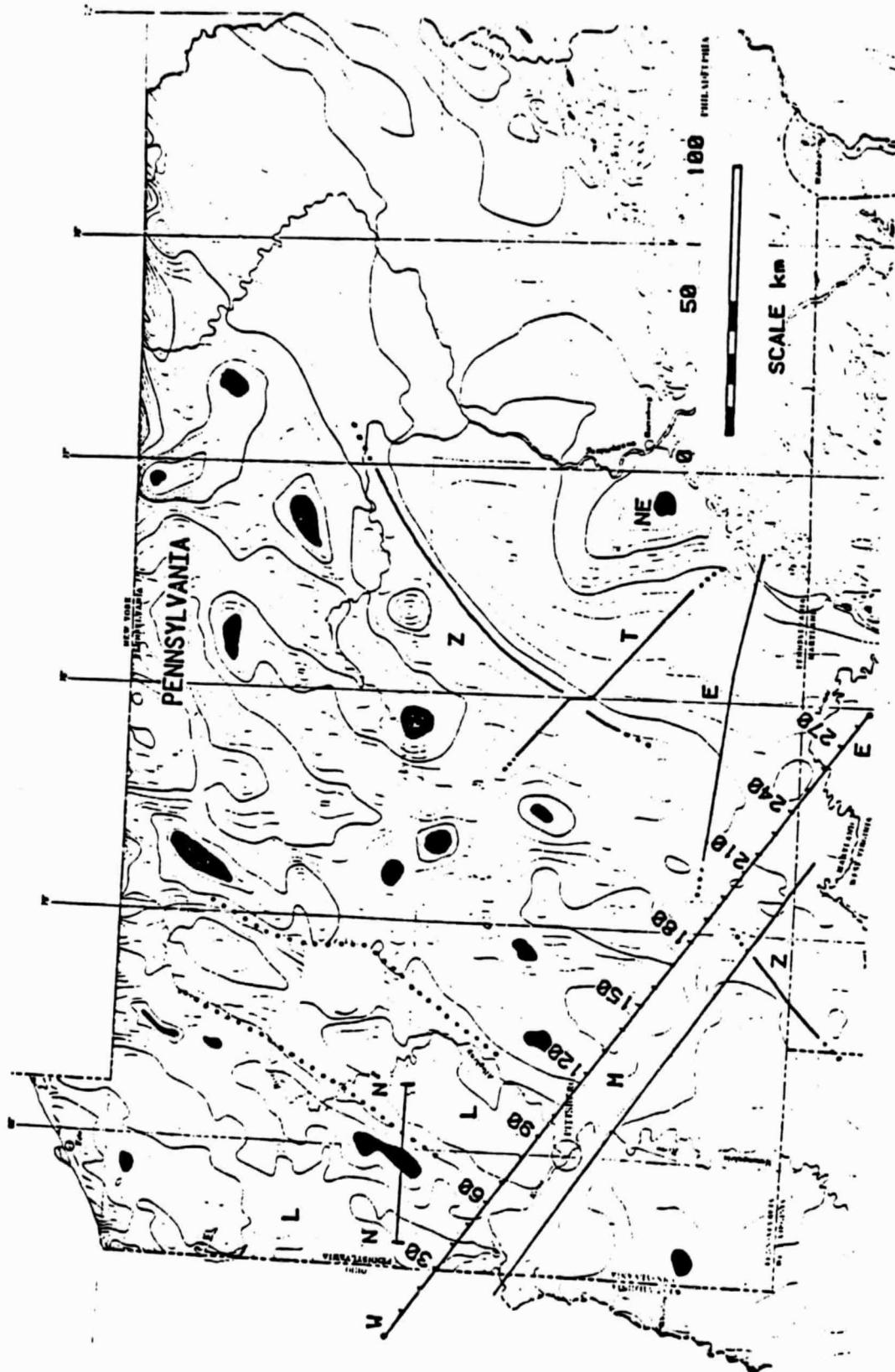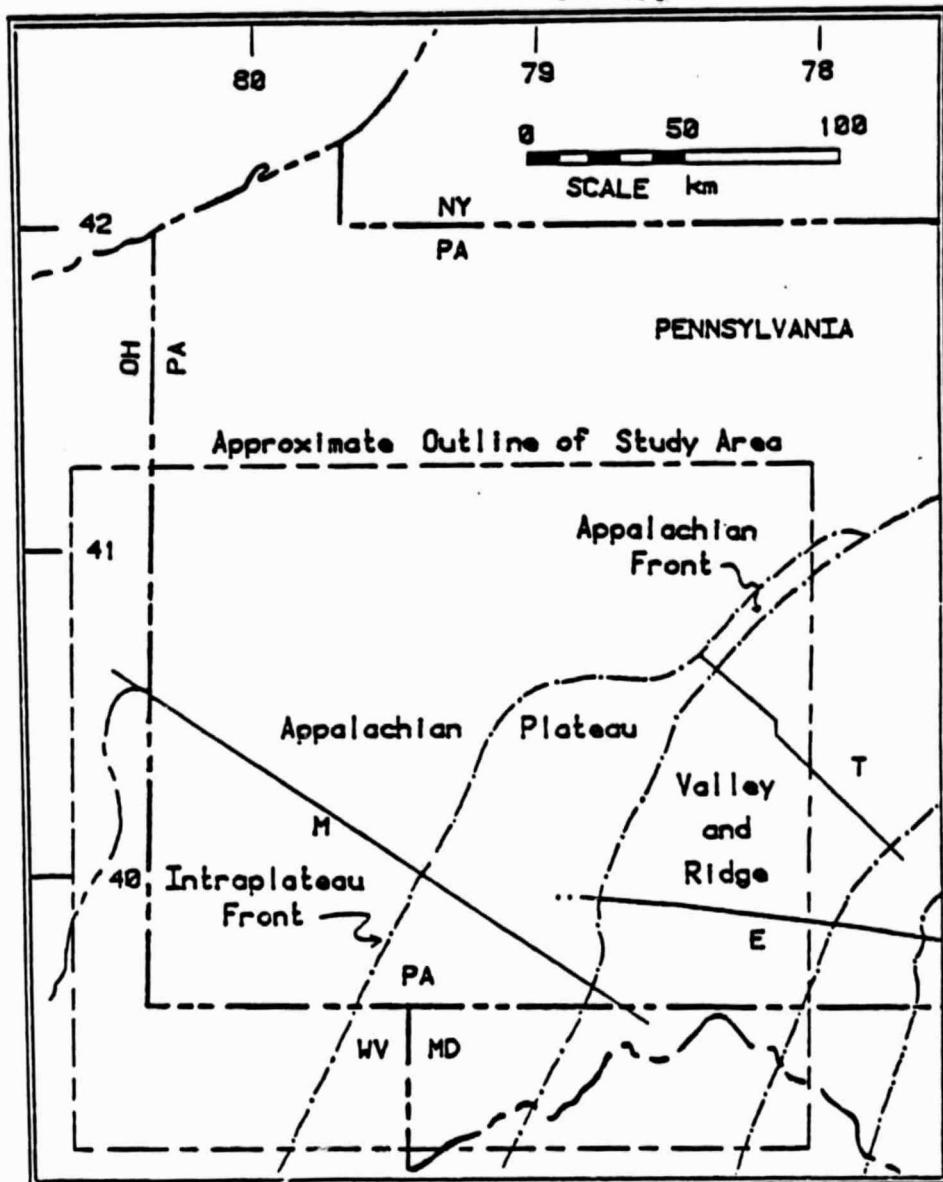
Figure 3. Location and geologic provinces of the primary study area. See text for symbol explanations.

Shield to central Alabama. Sediments accumulated to great thicknesses in this basin, possibly greater than 10 km along the deepest deposition axis (Root, 1973). Subsequent deformation, developed during several compressional episodes directed from the south and southeast, produced extensive folding and faulting within the sedimentary section.

The Folded Central Appalachian Mountains are characterized by gently curving, doubly plunging, and overturned anticlines and synclines alternating across a belt approximately 96-121 km wide (Gwinn, 1970). Here, first-order folds (about 11-18 km wavelength) are maintained in a variety of fold geometries including kink-band folds (Faill, 1969) and concentric folds (Gwinn, 1964).

The Folded Central Appalachians may be divided into two distinct physiographic provinces (Figure 3). The Valley and Ridge province is deeply eroded to expose intensely folded Cambrian, Ordovician, and Silurian limestones, dolomites, shales, and sandstones. Generally, thick Ordovician carbonate sequences are found in valleys which separate ridges peaking in resistant Silurian sandstones. In some cases, these ridges persist for distances in excess of 100 km with intermittent water and wind gaps.

Further west, relatively flat-lying Devonian, Mississippian, and Pennsylvanian rocks produce the dissected topography of the Appalachian Plateau province (Figure 3). This area is characterized by low intensity folding which decreases in intensity toward the west (Root, 1973).

The Appalachian Front (Price, 1931) is a structural boundary separating the exposed intense folding of the Valley and Ridge from the relatively mild folding within the Appalchian Plateau (Weaver, 1970). Folds, although steeply dipping or overturned, are continuous and substantially unfaulted across this zone (Root, 1973). Gwinn (1964) attributed the structural front to sole thrusts sheared upward from a Cambrian or Ordovician glide zone. A similar structure, the Intraplateau Front (Gwinn, 1964) is identified within the Plateau along Chestnut Ridge (Figure 3).

The Folded Central Appalachians were subjected to at least three orogenic events during Paleozoic time. About 80 km of Valley and Ridge cover shortening (Gwinn, 1970) is attributed to a terminal Paleozoic event, the Alleghenian orogeny (240-350 m.y. ago). The Acadian orogeny (320-350 m.y. ago) produced massive Devonian clastic wedges by uplifting the Piedmont region to the southeast (Root, 1973). An earlier event, the Taconic orogeny, involved similar tectonism in the Piedmont and the formation of a thick extensive carbonate clastic wedge. Radiometric dating indicates that the peak of Taconic deformation occurred about 450 m.y. ago (Root, 1973).

Two extreme views have been proposed regarding the style of Appalachian deformation and the relationship between the Paleozoic cover rocks and the underlying crystalline basement. The "thick-skin" hypothesis (Rodgers,

1949) asserts that folding and faulting within the basement
extended into the sedimentary rocks during orogenesis. In
addition, faulting and uplift to the east provided tectonic
source rocks which contributed to clastic wedges. Thus,
this hypothesis involves primary basement control of folding
(Cloos, 1949), faulting, deposition, and erosion. It is
assumed in the "thin-skin" hypothesis (e.g., Gwinn, 1964)
that Alleghenian shortening and thickening involved the
transport of Paleozoic sedimentary wedges along low angle
decollement faults in relatively incompetent Cambrian and
Ordovician units. However, the basement remained rigid and
undisturbed while these strata were transported above
(Gwinn, 1970). Generally, the necessary driving forces are
believed to result from gravitational collapse of
sedimentary cover away from the uplifted Piedmont (e.g.,
Root, 1973).

Geological and geophysical evidence seems to support
an intermediate model in which the basement does play some
role in the deformation overhead. For example, an
interpretation of seismic reflection data collected in the
Broad Top synclinorium of south central Pennsylvania
indicates that block faulting of planar basement and Lower
Paleozoic strata may have induced ramping or was somehow
related to decollement zones in higher sections (Jacobeen
and Kanes; 1974, 1975). The large COCORP seismic-reflection
survey (Cook et al., 1980), conducted in the southern
Appalachians, revealed a major subhorizontal thrust fault

extending from the Valley and Ridge to the Atlantic coastal plain. The rocks overlying this fault, including Precambrian rocks in the eastern physiographic provinces, have been displaced to the west at least 260 km. If the same geological conditions are found in the central Appalachians, however, this thrust sheet is confined to the sedimentary section and involves no basement rocks in the study area.

The similarity and coincidence of some basement structures and near-surface geological features has been reported in basement surface constructions (Chen, 1977; Kulander and Dean, 1978), although this argument may be somewhat circular for maps prepared solely from shallower stratigraphic data. Additional evidence is provided by studies which indicate that growth faulting and fault reactivation originating in the basement have controlled sediment distributions over time spans of several hundred million years (Wagner, 1976; Harris, 1978; Root, 1978).

Structures Identified in Previous Studies

The study area includes a number of crustal structures which have been identified in previous studies (Figure 4). The Rome trough is an extensive graben-like feature mapped in the basement of eastern Kentucky and West Virginia which will receive considerable attention in this study. As much as 1.5 km of vertical offset (Silberman, 1972) is developed in the basement along a growth fault found on the north side

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Figure 4. Crustal structures identified in previous
studies. Features and references are discussed
in the text.

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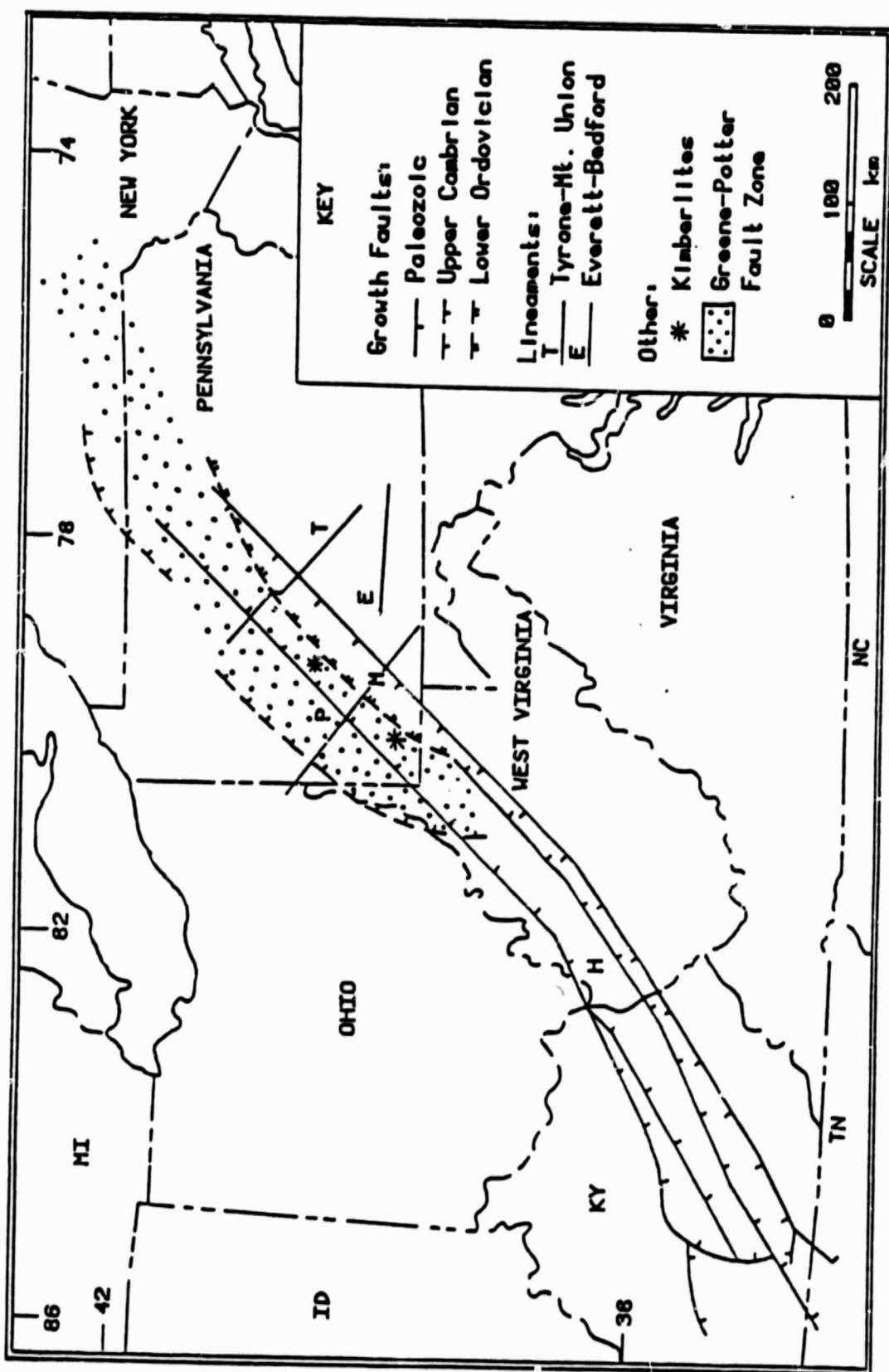
of the trough. It is believed that a continuation of the
Rome trough crosses West Viginia. Harris (1975) proposed
two down-to-the-east basement growth faults, based on
sedimentary evidence, which extend the Rome trough to the
Pennsylvania-West Virginia state line. Chen (1977), in a
compilation of deep well data, also concluded that the Rome
trough involves downdropped Precambrian basement rock and
anomalous thicknesses of Paleozoic sediments at least as far
northeast as the Pennsylvania-West Virginia state line.
Similarly, Kulander and Dean (1978) attributed a prominent
northeast trending magnetic low in the same area to an
extension of the Rome trough.

Several workers have presented evidence indicating
that the Rome trough may, in fact, continue through West
Virginia and into north-central Pennsylvania. Harris
(1978), in an examination of Cambrian through Mississippian
sediment distribution patterns, extended his earlier work to
define two Paleozoic vertical growth faults crossing western
Pennsylvania (Figure 4). Parrish (1978) has shown that this
area is a zone of crustal weakness. Root (1978) proposed a
similar zone of crustal weakness, the Greene-Potter fault
zone, characterized by a series of recurrent down-to-the-
east basement growth faults (Figure 4). Wagner (1976) also
suggested down-to-the-east growth faulting subparallel to
this in the Cambrian and Lower Ordovician sections of
western Pennsylvania (Figure 4).

Two major lineaments in the study area have been

associated with deep fracturing of the crust. The Tyrone-Mt. Union lineament (Gold et al., 1973) has been mapped in the Valley and Ridge using geological, geophysical, and remote sensing data ("T" in Figure 4). The Everett-Bedford lineament (Parrish, 1978) is defined in the Valley and Ridge by geological data ("E" in Figure 4). A strong magnetic gradient observed in the Appalachian Plateau has been suggested as a northwestern extension of this lineament ("M" in Figure 4).

CHAPTER III

STRUCTURES REVEALED BY
GRAVITY OBSERVATIONS AND MODELING

Introduction

Gravity data are used in this chapter to: 1) identify
or suggest structures producing the major gravity anomalies
in the study area, 2) obtain a more detailed structural
model of the crust, particularly the basement configuration,
beneath western Pennsylvania, and 3) to better locate faults
and subsurface topographic features identified in previous
studies (Chapter I).

Several observations suggest a useful approach to
modeling. Geophysical evidence indicates that, on a gross
scale, the crust may be subdivided into layers characterized
by rocks of distinct compositons and physical properties.
Although there is considerable variety within layers, the
average density increases with depth and there is reason to
expect sharp density increases across relatively narrow
boundaries between layers. For example, an abrupt density
increase is probably developed along the basement/sediment
contact, a profound unconformity, where relatively low
density sedimentary cover material, possibly anomalously low
due to initial depositional conditions on the basement
surface, overlies crystalline basement rocks of lower
porosity and denser mineralogy. The Moho contact is also

commonly described as a narrow and distinct transition zone separating the lower crust from the upper mantle.

Several seismic studies of crustal structure (e.g., Katz (1955), Ewing and Press (1959), Oliver et al. (1961), Dorman and Ewing (1962), and Isaacs (1979)) have presented inconclusive evidence regarding the existence of a lower crustal layer beneath western Pennsylvania and surrounding areas. Consequently, the inclusion of such a layer in gravity models may or may not be realistic.

The general appearance of regional gravity anomalies over western Pennsylvania indicates that the sources of these anomalies involve changes in the thickness of crustal layers rather than lithologic (i.e., density) changes within the layers. Magnetic anomalies are believed to reflect lithologic changes in the basement (Beck and Mettick, 1964). The very poor correspondence of gravity and magnetic anomalies observed in the study area supports this contention (Figures 1 and 2).

The relatively large areal extent of gravity anomalies over western Pennsylvania compared to those found in southern Ontario further supports this proposition. The basement rocks exposed in regions surrounding the study area (e.g. Saylor (1968), Espenshade (1970), Revetta (1970), and Chen (1977)) are similar in age and lithology, suggesting that the basement complex beneath southwestern Pennsylvania is comparable. In addition, gravtiy anomalies observed over the Grenville province of southern Ontario are believed to

be produced by lithologic changes in in the basement complex (Revetta, 1970). If crustal structure in southern Ontario, from the basement complex down, is similar to structure beneath the sedimentary cover in western Pennsylvania, then gravity anomalies of similar wavelengths should be observed in both areas.

With these assumptions and observations in mind, a two-dimensional gravity model was developed using a simple structure consisting of three constant density layers corresponding to the sedimentary cover, basement complex (upper crust), and lower crust. A section representing the lower crust was incorporated into the model to assure plausible density contrasts along the contacts between layers. A fourth layer, simulating the upper mantle, was also included to provide an appropriate density contrast along the Moho contact.

Gravity anomalies are attributed to relief along the layer interfaces in this modeling scheme. Although this seems to be a reasonable approach, models involving both relief along layers and density variations within layers might be more realistic. Some of these alternate solutions will be discussed.

The remainder of this chapter describes the development of a final gravity model and its use in the identification of structures. A preliminary cross-section was prepared utilizing published depth information. The gravity effect for this model was calculated and compared to

the observed data. The preliminary model was then modified,
using constraints imposed by previous work, to improve the
fit between the calculated and observed gravity.

Profile Line Selection

The profile line used for gravity modeling is 285 km
in length and strikes about S37E beginning near 80.75 W and
41.06 N and ending at about 78.07 W and 39.50 N (line WE in
Figure 1). This particular line approximately bisects the
major regional gravity anomalies within the study area, is
subparallel to magnetic profiles used by Davis (1980) in a
study of the basement, and is oriented nearly perpendicular
to regional structure (i.e., in a direction which should
show the maximum gradients developed by regional structure).

Bouguer gravity values were selected from a 40 km
strip centered on the profile and projected into the profile
line (Figure 5). An average curve through the data was
determined and sampled at 3 km intervals to provide
"observed" values for modeling purposes. A fit within 2 or
3 mgals to the average curve falls within the scatter of the
data and therefore is taken as a reasonable fit. It should
be noted that those regions exhibiting unusually great
scatter are less suitable for two-dimensional modeling; that
is, the pattern of observed anomalies suggests that a three-
dimensional model is required.
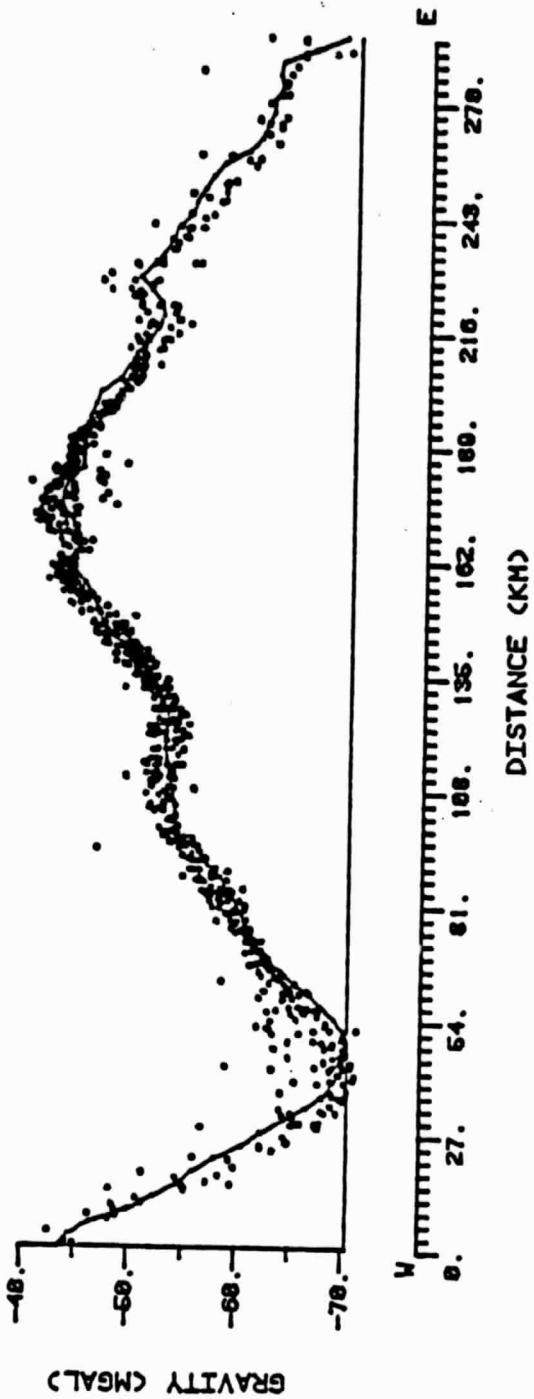
Figure 5. Average gravity curve along profile WE and 865 stations projected into the profile from a 40 km strip centered on the profile line.

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Choice of Densities

Density data were collected from a variety of sources to obtain values for modeling the various rock types in the crustal section. Data for shales, limestones, dolomites, sandstones, and siltstones found in the sedimentary section of the Appalachian Plateau and Valley and Ridge have been compiled by Kulander and Dean (1978), Daly (1966), and Revetta (1970). Their values generally range from 2.60-2.71 g/cc with an average of about 2.66 g/cc.

A review of isopach maps for sedimentary units with densities outside this range revealed no sections or recurrent deposition axes thick enough to produce sufficient structural relief to deflect the average gravity curve outside of the scatter shown in Figure 5. In addition, the few intrusive rocks exposed within the study area probably make little contribution to regional gravity patterns. Consequently, the average density suggested above, 2.66 g/cc, was assumed for the sedimentary section in gravity modeling.

Although the basement beneath western Pennsylvania has been sampled in only three deep wells, it is generally believed that these Precambrian rocks are similar in composition and structure to the Grenville age basement complex exposed and sampled in adjacent areas (Saylor, 1968). Thus, the basement probably consists of various crystalline metamorphic and igneous rocks which have been repeatedly intruded to produce a "patchwork" distribution of

compositions.

Many of these rock types, including anorthosites, diorites, basalts, gabbros, phyllites, gneisses, and amphibolites, typically have densities which are greater than those of the cover rocks. Other basement rock types, noteably granites, granodiorites, syenites, rhyolites, and schists, generally have densities in the range of the cover rocks. The basement measurements reported by Oliver et al. (1961), Woollard (1962), Revetta (1970), Telford et al. (1976), and Stacey (1977) are similar and suggest that a value of 2.76 g/cc is appropriate for gravity modeling.

Seismic observations suggest that the lower crust consists of mafic rocks such as gabbro/basalt, peridotite/dunite (Pakiser and Zietz, 1965), quartz-diorite (Tarling, 1978), and possibly amphibolite. These conclusions are based on seismic calculations indicating an average lower crust density of about 2.94 g/cc (e.g., Oliver et al. (1961) and Stacey (1977)). This value is used in the gravity models.

The mafic rocks of the lower crust are probably underlain by ultramafic material in the upper mantle. Inferred compositions include very dense rock types such as peridotite, eclogite, and dunite. A modeling density of 3.30 g/cc was selected to represent these rocks as indicated by numerous studies, including Katz (1955), Worzel and Shurbet (1955), Drake et al. (1959), Talwani et al. (1959a), Woollard (1959), Oliver et al. (1961), Dorman and Ewing

(1962), Woollard (1966), Ringwood (1969), and Stacey (1977).

Choice of Depths

Depth data were collected from a variety of sources and combined with the density values discussed above to prepare the preliminary crustal section shown in Figure 6. The top of the basement surface was determined by modifying the basement profile constructed, using magnetic depth estimations, by Davis (1980). Davis' section was altered to satisfy additional magnetic depth estimates prepared by Beck and Mettick (1964) and Kulander and Dean (1978), seismic reflection profiles reported by Gwinn (1970) and Jacobeen and Kanes (1974, 1975), and deep well information reported by Wagner (1976), Chen (1977), Kulander and Dean (1978), and Lavin (1980). Generally, the western half of the profile is more poorly constrained than the eastern half, since the data are scarce there. The reliability of the basement depths assumed in the preliminary section is indicated by the dashed portion of the basement surface shown in Figure 6.

The depth of the upper crust/lower crust transition contact, if present, is uncertain. For modeling purposes an average depth of 17 km was assigned based on a calculation assuming a partitioned crust with an average density of 2.85 g/cc (Katz (1955), Worzel and Shurbet (1955), Woollard (1959), Dorman and Ewing (1962), and Ringwood (1969)). This value is within the range of depths suggested for the Conrad
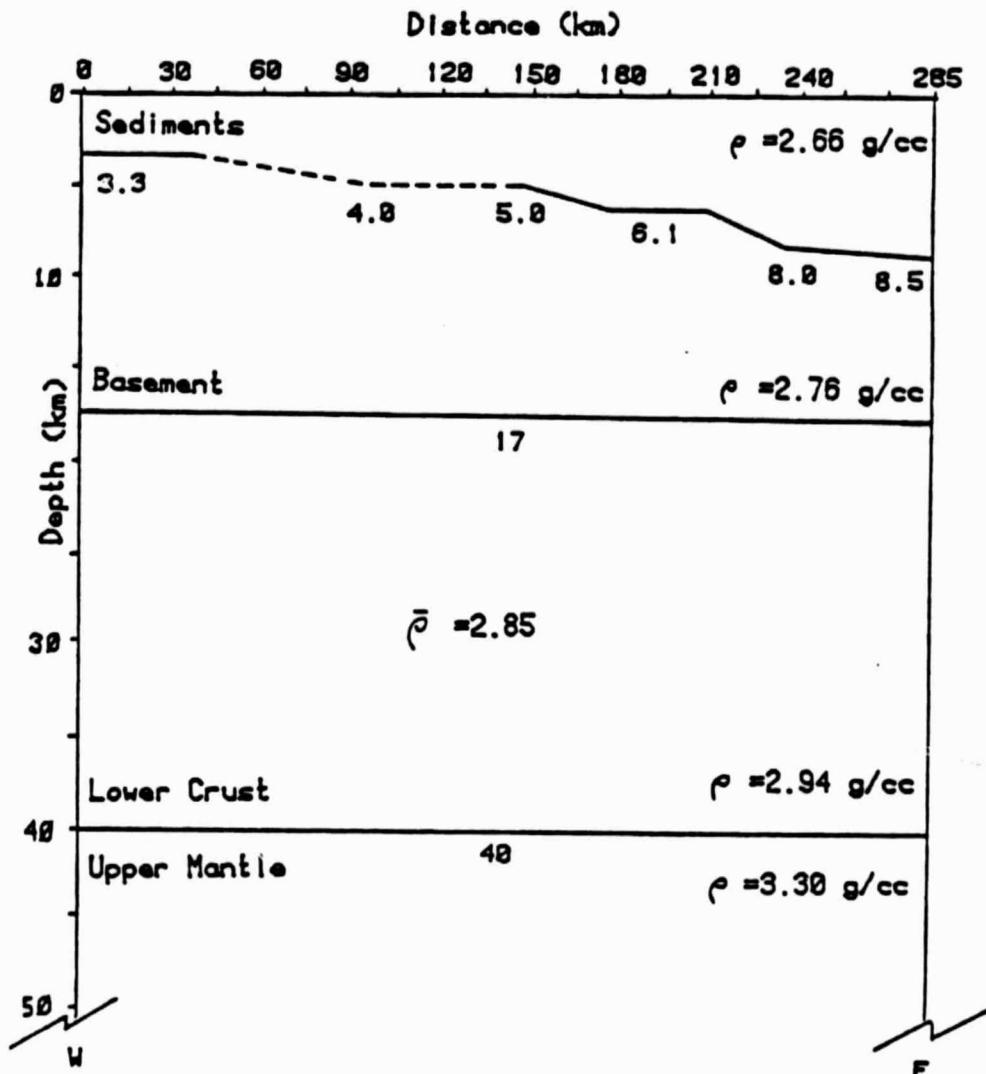
Figure 6. Preliminary crustal section along profile
line WE showing initial model densities and
depths. Average crustal density is 2.85 g/cc.

discontinuity beneath the study area by Lyons (1970) and
Wyllie (1971).

The depth of the Moho discontinuity dividing the lower
crust and upper mantle is somewhat better known. A review
of seismic studies by Katz (1955), Ewing and Press (1959),
Oliver et al. (1961), Dorman and Ewing (1962), and Isaacs
(1980) suggests that an average Moho depth of 40 km is
reasonble for modeling purposes.

Gravity Modeling

The preliminary crustal section (Figure 6) was used as
a starting point for subsequent gravity modeling. The
procedure described by Talwani et al. (1959b) was used to
compute the gravity profile developed by the preliminary
section. A very poor fit of calculated and observed values
resulted. The preliminary crustal section was therefore
modified, within constraints imposed by available data, to
obtain an improved fit. The resulting model (Figure 7) was
obtained by detailed analysis of the major gravity anomalies
in the study area. This process is described in the
following sections.

Beaver Falls gravity low. A major gravity anomaly,
herein called the Beaver Falls gravity low, dominates the
western part of the profile ("BF" in Figures 1 and 7). This
anomaly is somewhat asymmetrical, showing a steeper gradient
on its west flank. Assuming the regional trend suggested by

Figure 7. Model of crustal structure for southwestern
Pennsylvania showing observed and calculated
gravity values and the densities and depths
assumed. Labeled anomalies are described in
the text.

ORIGINAL PAGE IS
OF POOR QUALITY

GRAVITY (MGAL)

DEPTH (KM)

DISTANCE (KM)

Observed
Calculated

MA
CH
SO
GR
BF

E
W

2.66 g/cc
2.76 g/cc
2.94 g/cc
3.30 g/cc

8.5
8.8
6.1
5.5
7.2
5.5
8.5
3.3

18.2
17.2
18.4
17.2
21.6

39.4
40.0
40.0

-40.
-50.
-60.
-70.

0.
-10.
-20.
-30.
-40.
-50.
-60.

0.   27.   54.   81.   108.   135.   162.   189.   216.   243.   270.
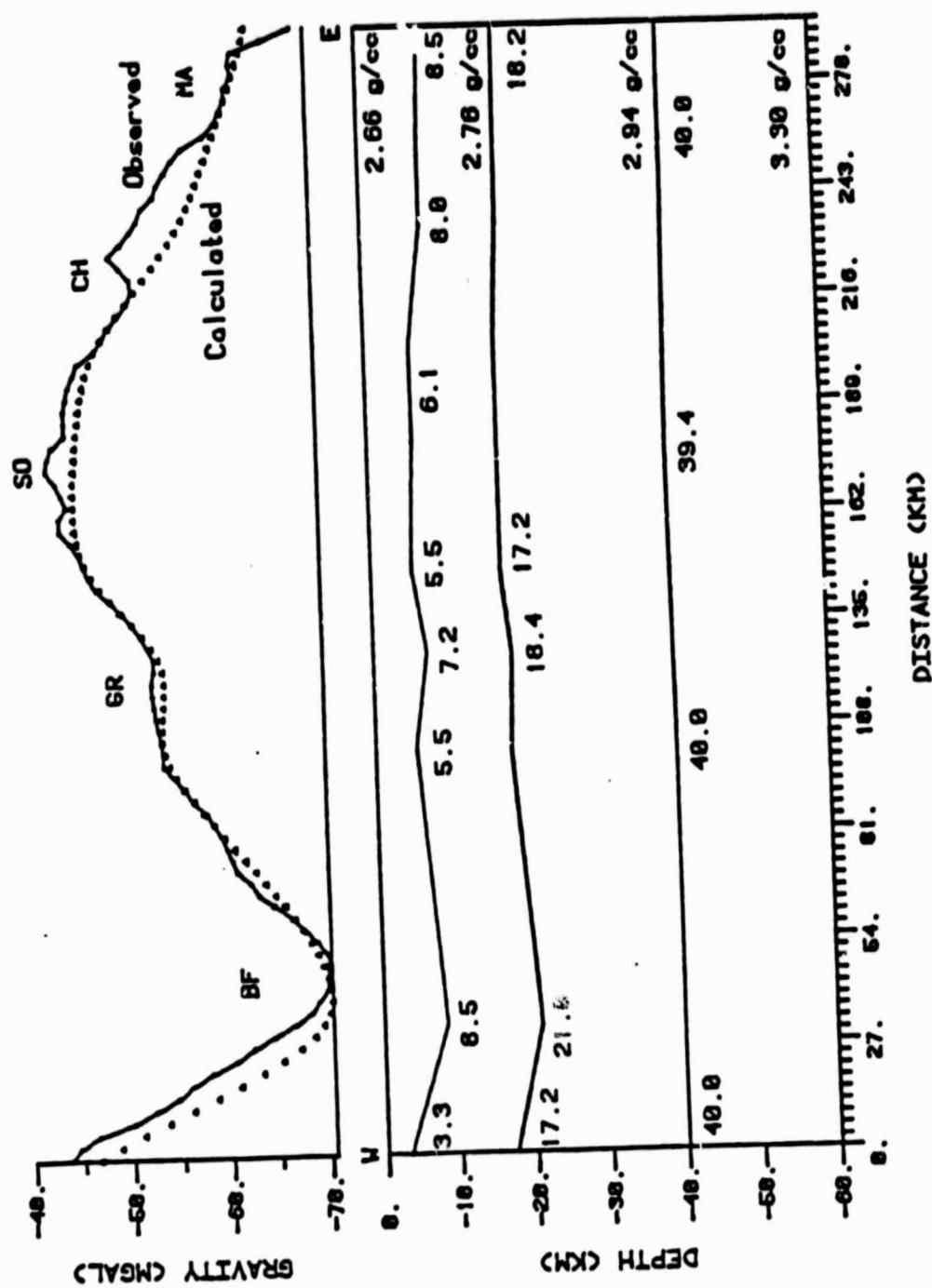
Woollard (1966) for a transcontinental survey, the wavelength of this feature confines its source to depths shallower than about 24 km; certainly it is within the crust.

Woollard's (1943) original transcontinental survey traversed the southern portion of the Beaver Falls low. In a preliminary analysis, he suggested a Paleozoic sedimentary basin source for this anomaly, since a regional magnetic low is also developed there. Additional geophysical evidence supports the sedimentary basin/basement low hypothesis. The magnetic low described by Woollard (1943) exhibits over 500 gammas of total relief north of Pittsburgh ("L" in Figure 2). A comparison of gravity and magnetic data along the profile line (Figures 1 and 2) shows the general coincidence of this magnetic low and the Beaver Falls gravity low. A sharp magnetic peak in this area (Figure 2) may reflect a lithological change in the basement or possibly a volcanic flow along the basin floor. Davis (1980) reported that anomalously deep basement could be indicated by a zone of "correlated magnetization" in the same area (shown by region between dotted lines in Figure 2). Negri (1975) defined a northeast-trending basement low beneath the northeast flank of the Beaver Falls gravity low,based on magnetic depth interpretations. He suggested maximum basement relief of about 2.1 km there (basement low shown along profile line NN' in Figure 2).

The author further tested the basin idea, using the

statistical depth estimation technique ADEPT (Phillips,
1978). The method was applied to magnetic data sampled at
1.6 km intervals along the profile line. Although the
results must be considered preliminary, a smooth easterly
descending basement surface was indicated along the west
flank of the Beaver Falls gravity low near the Pennsylvania-
Ohio state line. Assuming that the axial magnetic high
described earlier represents a lithologic change and not
extreme basement relief, a projection of the descending
surface to the central low of the Beaver Falls anomaly
suggests a basement trough whose depth may be greater than
8.5 km. ADEPT profiles calculated for larger sample
intervals yielded somewhat shallower estimates so the 8.5 km
estimate may represent a maximum depth.

Additional geological evidence suggests the presence
of a sedimentary basin beneath the Beaver Falls gravity low.
Rodgers (1963) has described a major structural basin, the
Pittsburgh-Huntington basin, which is distinct from the deep
Appalachian basin found to the east and which trends between
Pittsburgh and Huntington, West Virginia, roughly parallel
to the West Virginia-Ohio state line. This area coincides
with a zone of northeast-trending Permian rocks, among the
youngest preserved in the Appalachian Plateau. These rocks
are shown in a gentle basin structure on a cross-section
included with the current Geologic Map of Pennsylvania (Gray
et al., 1979). An isopach map of the Upper Cambrian (Chen,
1977) shows a deposition axis centered over northwest West

Virginia trending parallel to the Ohio-West Virginia state
line and continuing beneath the Beaver Falls gravity low.
Here, Upper Cambrian sediments approximately 0.45 km thick
are distributed in a pattern resembling the shape of the
anomaly. Data for the Lower and Middle Ordovician are not
available and a similar distribution pattern for these units
cannot be ruled out. The Beaver Falls gravity low may also
mark the Olin basin described by Wagner (1976).

A comparison of the Beaver Falls structure with the
Rome trough can be made. The Rome trough generates about 15
mgals relief (Ammerman and Keller, 1979) and includes over
2.6 km of Cambrian sediments along the Kentucky-West
Virginia state line. A deep well, drilled over the southern
flank of the Beaver Falls anomaly, penetrated the Upper
Cambrian section at about 4.7 km. Assuming a thickness of
Cambrian sediments comparable to that in the Rome trough, it
is conceivable that a sedimentary basin below Beaver Falls
could attain depths in excess of 7.4 km. Similarly,
assuming vertical faulting, as indicated in the Rome trough,
a typical sediment density of 2.66 g/cc, and the observed
gravity relief for the Beaver Falls anomaly, a graben
structure achieving a maximum depth of 8.3 km is plausible.

The preliminary crustal section was first modified to
accomodate the Beaver Falls gravity low. Assuming the model
densities obtained earlier, simple basement models in which
the anomaly is attributed to a sedimentary basin required
over 13 km of fill to produce a satisfactory fit of observed

and calculated gravity. This depth is approximately twice the value expected, based on the analysis presented above, and is unusually deep for this area. Therefore, the basement depth suggested by ADEPT calculations (8.5 km) was assumed and the upper crust/lower crust break was shifted 3.8 km deeper to provide a close gravity fit.

The role of the Moho contact and upper mantle beneath this basement low, if any, is not known. However, Woollard (1966) has suggested that, as a general rule, gravity anomalies with wavelengths in the range 30-60 km are related to local geological changes which are essentially uncompensated. It would seem that the Beaver Falls anomaly involves little change in crustal thickness.

Greensburg gravity low. The Greensburg gravity low ("GR" in Figures 1 and 7) defines a northwest-trending zone about 60 km wide between the Beaver Falls anomaly and the Somerset gravity high at the center of the profile line ("SO" in Figures 1 and 7). The relatively small wavelength of this anomaly confines its source to depths shallower than about 11 km.

The source of the Greensburg anomaly appears to involve basement structures. A comparison of gravity and magnetic profiles over the anomaly reveals coinciding lows. In addition, isopach maps of the Lower Middle Ordovician (Chen, 1977) include a deposition axis which coincides with the Greensburg anomaly. Perhaps this anomalous

sedimentation marks a basement trough reactivated during
Lower Middle Ordovician time.

Initial models showed that, if the Greensburg anomaly
is attributed entirely to relief along the basement/sediment
contact, a basin with a maximum depth over 8 km is required
to fit the observed data. However, the absence of a
magnetic low over the Greensburg gravity low comparable in
magnitude to the magnetic low over the Beaver Falls gravity
low could indicate that basement lows of similar depths are
not developed in these areas. Consequently, the basement
complex/lower crust contact was deflected to permit
shallower depths. A basin with over 1 km depth was modeled
here (Figure 7).

Somerset gravity high. The axis of the Somerset
gravity high ("SO" in Figures 1 and 7) coincides with the
peak near the midpoint of the gravity profile. The
relatively large wavelength of this anomaly could be
generated by sources at any depth within the crust.
Although several Lower Paleozoic deposition axes are
developed here, about 2.6 km of anomalously dense (2.76
g/cc) carbonates would be required to produce the observed
gravity anomaly. Such thicknesses were not found in
available isopach data. Nettleton (1941) has suggested
deeper sources for this gravity high. It is noteable that
there is a poor correspondence between gravity and magnetic
patterns in this area. Possibly a source below the Curie

depth (approximately 25 km) is involved.

The basement section beneath the Somerset gravity high was not modified since it is fairly well-constrained by deep well data. Although this area marks a regional basement high, the gravitational relief developed without alteration of the gravity model was insufficient to provide a fit of the observered gravity. As a result, a small upward deflection (0.6 km) of the upper mantle was incorporated into the model to improve the fit. The three-dimensional character of the Somerset anomaly, evident in Figure 5, indicates that a more careful fit is not useful here. Woollard (1966) has suggested that anomalies of intermediate wavelergth (100-300 km) may involve crustal displacements of tectonic origin.

Chaneysville gravity anomaly. The Chaneysville gravity anomaly ("CH" in figures 1 and 7), although not well-resolved, is a persistent northeast striking feature. The anomaly consists of a narrow gravity high flanked on the west by a narrow gravity low. The wavelengths of these disturbances confine the source of this anomaly to the sedimentary section.

Kulander and Dean (1978) studied a similar gravity anomaly in West Virginia. Detailed gravity modeling indicated that a 3 to 6-mgal high over Warm Springs anticline was produced by tectonically thickened and relatively dense carbonate units over a Cambrian decollement

ramp. A 2 or 3-mgal low found immediately to the west is located over stacked low density shales along the Appalachian Front. The Chaneysville gravity high and corresponding gravity low are located over Tussey mountain and the Appalachian Front, respectively, in south central Pennsylvania. It appears that similar structural settings produced the anomalies observed in both areas. The preliminary section was not modified beneath the Chaneysville gravity high since the source is confined to the sedimentary section. Thus, the fit of calculated to observed gravity shown in Figure 7 does not reflect the influence of the anomalously dense units along this portion of the curve.

Martinsburg gravity low. Inspection of the regional gravity map of the U. S. (Woollard and Joesting, 1964) shows that the Martinsburg low ("MA" in Figures 1 and 7) is part of a strong, broad northeast-trending gravity low (with total relief greater than 30 mgals) which extends the length of the Appalachian Mountain system. Locally, this low crosses through Martinsburg, West Virginia and Franklin county in Pennsylvania where it attains a minimum of -80 mgals.

The broad wavelength of this anomaly could reflect a source or sources deep within the crust. Woollard (1943) has suggested that the source of this anomaly might involve a deep Paleozoic sedimentary basin (perhaps with

overthrusting of sediments by basement rocks) and/or
increased crustal thickness possibly due to a mountain root
or crustal downbuckle.

A basement low probably does contribute to this
anomaly. Gwinn (1970) has reported basement depths in
excess of 8 km in this area (east end of profile in Figure
6), among the deepest in the Appalachian basin. The western
flank of the gravity anomaly (-60 mgal contour in Figure 1)
overlies an eastward decreasing magnetic gradient (Figure
2). These associations suggest an asymmetrical basement low
whose geometry is similar to the known sedimentary thickness
distribution.

However, anomalously low heat flow (possibly
indicative of thickened crust), which is characteristic of
the Valley and Ridge (Diment et al., 1972), suggests the
involvement of deeper sources in addition to the
disturbances suggested in the upper crust. Further, the
steep eastern flank of the anomaly nearly coincides with the
western edge of exposed Precambrian rocks and has been shown
to have a source within the crust (Griscom, 1963).

Final modifications were made to the crustal section
beneath the Martinsburg low. A close fit is not meaningful
since the observed gravity curve is defined by few data
points here (Figure 5). Increased "Conrad" depths might be
appropriate since the basement is extremely deep. A 1-km
increase in the upper crust/lower crust contact was
incorporated into the model to improve the gravity fit since

the top of the basement is fairly well constrained by seismic reflection data (Gwinn, 1970).

Alternate Solutions

The final model (Figure 7) was constructed assuming constant density layers to represent crustal structure. A significant result of this approach was that substantial topographic relief was necessitated along an assumed "Conrad" discontinuity to prevent unreasonable relief on the top of the basement. Perhaps th 'ectonic mechanisms which produced the sedimentary basins modeled here also displaced the Conrad discontinuity.

Alternatively, perhaps some type of density change, not incorporated into the models, is developed within the basins. An example is provided by the Rome trough where substantial thicknesses of Cambrian sediments with anomalously low densities (around 2.51 g/cc) were reported by Ammerman and Keller (1979). To date, the Lower Cambrian section beneath the study area has not been sampled by deep wells. If an extensional tectonic setting produced the basement lows in the study area, as was the case for the Rome trough (Harris, 1978), then low density clastic fill might be expected there.

The representation of such material in gravity models could eliminate the need to deflect the assumed Conrad discontinuity and the Beaver Falls low, Greensburg low, and Martinsburg low could be attributed entirely to basement

structures. This alternate modeling scheme does not,
however, significantly change the basement configuration
depicted in Figure 7.

Relationship of Model to Known Structures

The basement/sediment contact suggested by gravity
modeling (Figure 7) is not the gently eastward dipping
surface commonly portrayed in previous studies. This is
particularly true along the western half of the profile
where the basin beneath the Beaver Falls gravity low may
attain a depth in excess of 8 km. Figure 8 displays several
known features believed to be related to basement
structures. The relationship between these structures and
the gravity model described in this chapter is discussed in
the following sections.

The Rome trough. Several observations indicate that
the Rome trough may continue into Pennsylvania as the
basement low modeled beneath Greensburg. The inferred trend
of the trough in West Virginia (Figure 4) is on- strike with
the Greensburg low. In addition, the width and depth of the
modeled low is about the same as those of the Rome trough in
West Viginia.

It is also possible that the Rome trough is
represented by the gravity anomaly over Beaver Falls. The
location of bounding faults proposed by Harris (1978) must
be considered highly speculative, since they are not
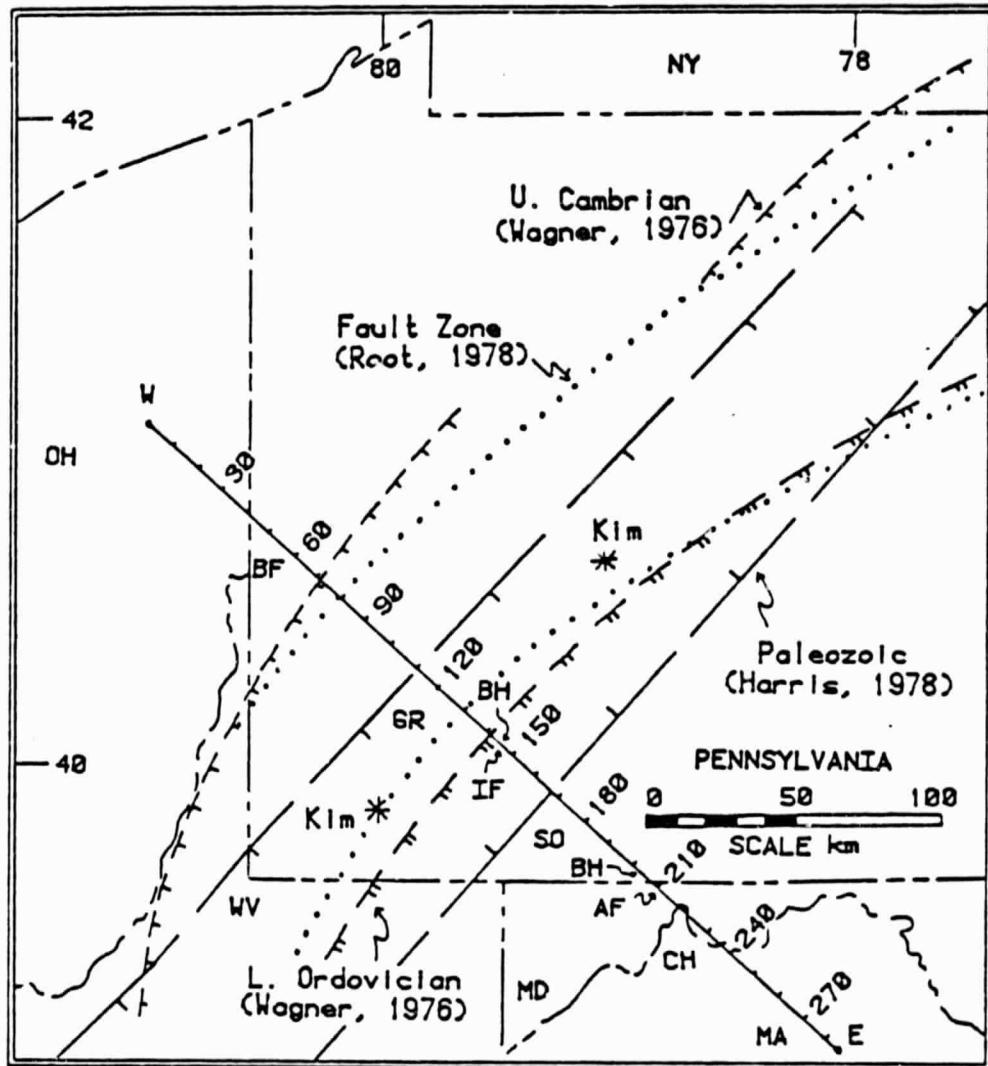
Figure 8. Basement features beneath western Pennsylvania.
Distances along profile line WE in km.

strongly reflected in the generalized isopach maps from
which they were inferred. A magnetic low associated with
the Rome trough in West Virginia (Kulander and Dean, 1978)
is deflected west of the Harris faults. An isopach map of
the Lower Cambrian (Wagner, 1976) includes similar
deflections. A review of detailed isopach maps (Chen, 1977)
for southern Pennsylvania and northern West Virginia did not
reveal a sedimentary basin that was persistent through
geologic time between the Harris faults. In addition, a
major left-lateral crustal offset, described in the next
chapter, might have resulted in a westward displacement of
the Rome trough.

Other structures. Growth faults inferred by Wagner
(1976) may mark border faults of the basement low modeled
beneath Beaver Falls. The location of a down-to-the-east
Upper Cambrian growth fault is virtually unconstrained along
the Pennsylvania-West Virginia state line. A shift of this
fault to the western flank of the Beaver Falls basement low
is reasonable and, in fact, Wagner (1976, Figure 6)
indicated some westward deflection of Upper Cambrian isopach
lines here. The Lower Ordovician down-to-the-east growth
fault is better-constrained. A slight westward shift would
locate this fault close to kimberlite intrusions near
Masontown and Dixonville (Figure 8). These kimberlites were
probably intruded from sources at great depths (Parrish,
1978). Perhaps the development of this major growth fault

involved kimberlite intrusion. Another possibility is that the Lower Ordovician fault is more nearly coincident with the western flank of the Greensburg basement low.

Alternatively, the smooth gradients displayed in the major gravity anomalies may reflect an extensive series of parallel, northeast-trending basement faults which do not individually preserve the large displacements suggested by the faults Wagner and Harris mapped, but collectively produce deep sedimentary basins. Root (1978) concluded that anomalous sedimentary distributions could be explained by such a series of faults. These faults and the kimberlites near Masontown and Dixonville define a northeast-trending zone of crustal weakness in central Pennsylvania (Figure 8) which has been intermittently active during Paleozoic and Mesozoic time. Parrish (1978) has proposed a similar zone of crustal weakness in his analysis of kimberlite emplacement.

Two minor basement highs were modeled over the eastern half of the profile line (Figure 7 and "BH" in Figure 8). Their culminations, within 10 km of the Appalachian and Intraplateau fronts, respectively, may indicate the locations of basement features related to structures developed in the sedimentary cover. Cross-sections from the Geologic Map of Pennsylvania (Gray et al., 1979) also show basements highs near these fronts in the center of the Commonwealth. A similar relationship was noted between the Central West Virginia Arch, Eastern West Viginia Arch,

Intraplateau Front, and Appalachian Front by Kulander and Dean (1978). Possibly, down-to-the-east faults (Jacobeen and Kanes, 1975) are unresolved in the descending region between 208-235 km along the profile line (Figure 7).

CHAPTER IV

MAJOR LINEAMENTS AND THE

THE LAKE ERIE-MARYLAND CRUSTAL BLOCK

Introduction

A number of workers have suggested that the study area
includes crustal blocks of various thicknesses and widths.
In particular, Rodgers (1964) presented a model in which
western Pennsylvania included at least two major sedimentary
blocks. Parrish (1978) extended Rodgers' work citing
gravity and magnetic evidence to define a block including
the basement and possibly the entire crust. He suggested
that this block terminated along the Tyrone-Mt. Union and
Everett-Bedford lineaments to the northeast and southwest,
respectively. This idea is further developed in this
chapter. The known bounding lineaments are redefined and/or
extended in length, and the evidence suggesting that these
lineaments mark deep crustal fractures is presented.
Additional evidence indicating that the lineaments and the
crustal block between them has been offset is also
discussed.

The Tyrone-Mt. Union Lineament

The Tyrone-Mt. Union lineament (Gold et al., 1973) is
strongly expressed in the Valley and Ridge of central
Pennsylvania by the alignment of surficial structures in a

0.5 to 2.0-km wide zone striking across regional geologic trends (Figure 9). These structures include water and wind gaps, the anomalously trending linear branch of the Little Juniata river, which cuts across anticlinal structures and resistant beds through rocks of different erosional competence, valley segments, sag alignments, vegetation growth anomalies, tonal variations (Canich and Gold, 1977) and at least one strike-slip fault (Gray et al., 1979). This zone is also characterized by increased fracture density and geometrically related faulting and jointing (Canich and Gold, 1977), Pb-Zn and Cu mineralization (Smith et al., 1971), plunging anticlines (Kowalik, 1975) and termination of third and fourth order folds and faults (Canich and Gold, 1977).

Canich and Gold (1977) concluded that the evidence in the Valley and Ridge province indicates that the Tyrone-Mt. Union lineament is a buried fracture zone whose surface expression is controlled by currently active Precambrian structures and which acted as a domain boundary during Alleghenian cover shortening. Geophysical evidence presented here and base mineralization developed along the lineament (Smith et al., 1971) support a projection of the surficial features described above to the Precambrian basement and possibly to greater depths.

The Tyrone-Mt. Union lineament may be extended into adjacent physiographic provinces using geophysical evidence where surficial signatures are obscure or absent. Major

Figure 9. Location of the Tyrone-Mt. Union and Everett
   lineaments.

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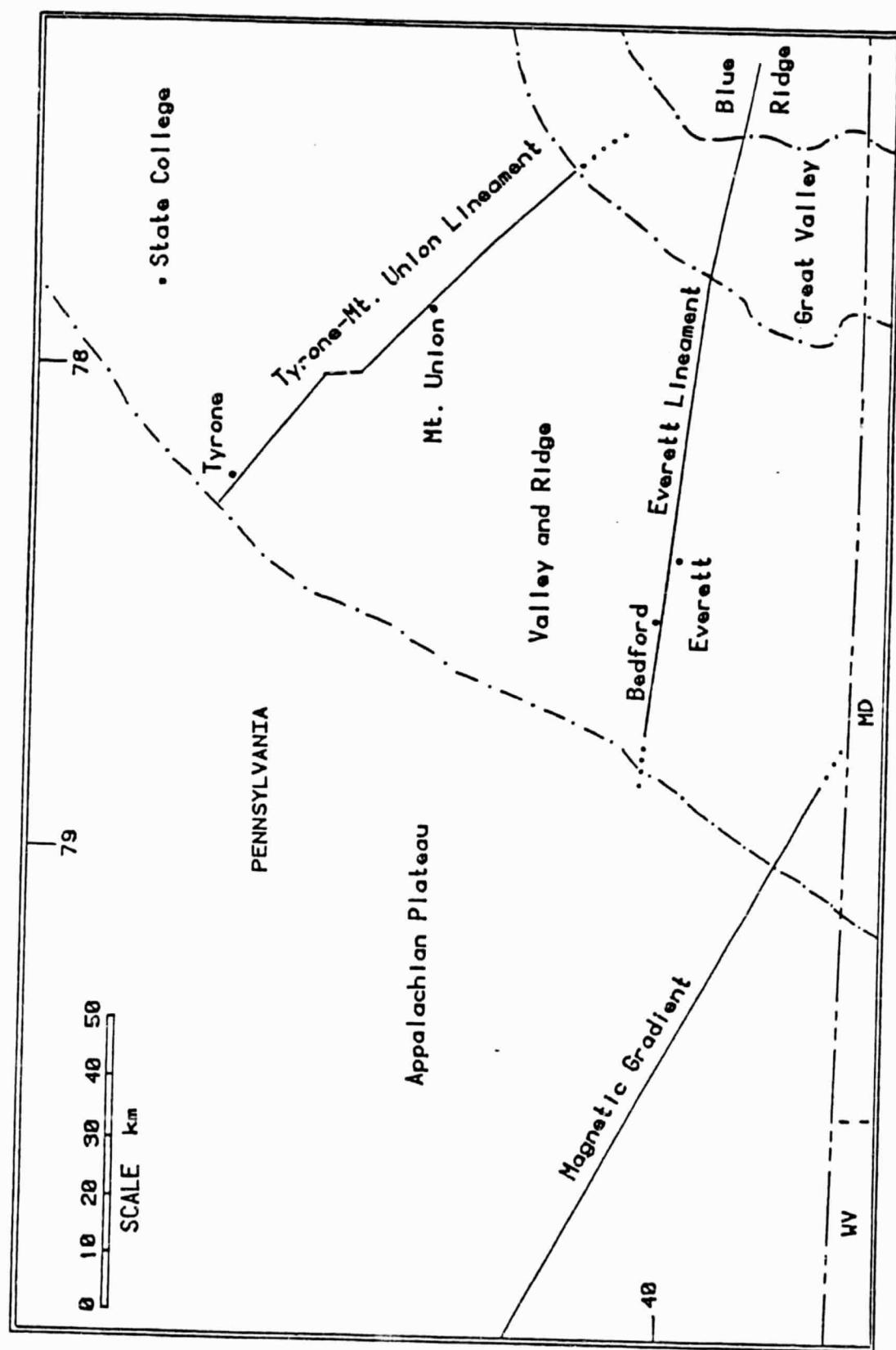
gravity anomalies in the Apalachian plateau, including the Greensburg low, Somerset .igh, and Kane high ("GR", "SO", and "KA", respectively. in Figure 1) appear to be interrupted along a northwest-trending zone which is nearly on-strike with the lineament developed in the Valley and Ridge (approxima e outline of these anomalies shown in Figure 10). T:rminations, interruptions and anomalous trends are oserved in magnetic data along the same trend (Figure 2,. A well-expressed lineament, greater than 40 km in ler ch, which crosses Crawford county beginning near Tit sville (Kowalik, 1975) is also on-strike with the li eament developed to the east ("L" in Figure 10). These observations indicate that the Tyrone-Mt. Union lineament is a continuous structure extending to the northwest at least as far as Lake Erie.

The lineament also appears to extend to the southeast along the steep southwest flank of the Newport gravity and magnetic high ("NE" in Figures 1, 2, and 10). A map of the Precambrian basement in this area, inferred from stratigraphic projections (Chen, 1977), shows the 20,000 foot contour is disrupted in this zone which suggests that the lineament is associated with basement rocks here.

There is additional evidence which suggests that the lineament or possibly a related structure persists in the crust of coastal states and probably offshore. Saddle-like and straight-edged magnetic anomalies (Zietz et al., 1980) characterize a zone approximately coincident with the

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Figure 10. Evidence suggesting possible extensions of the
Tyrone-Mt. Union lineament and defining the
Pittsburgh-Washington lineament.
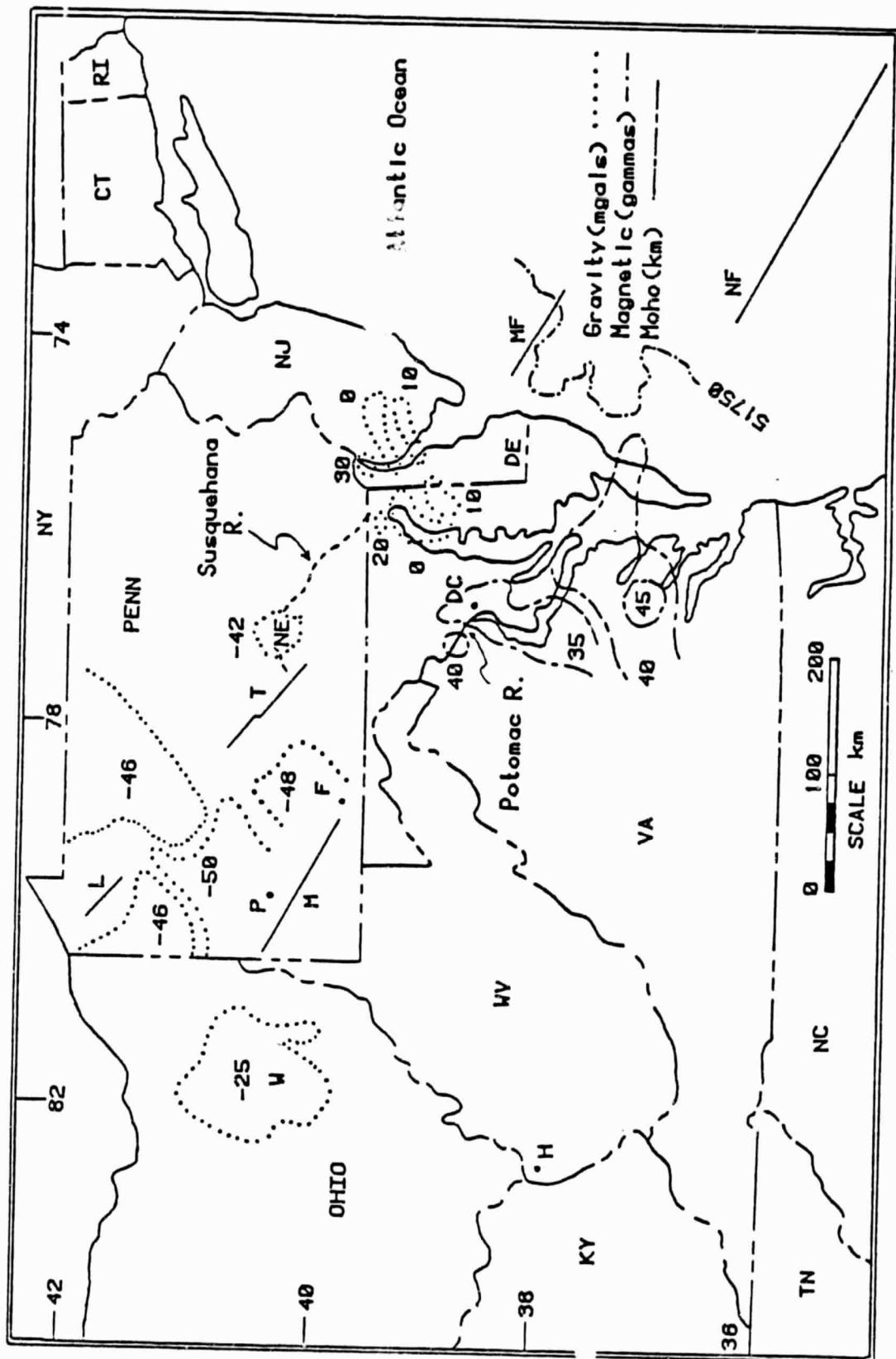
southern shore of the Delaware Bay. Gravity anomalies are
interrupted in the same region (Figure 10). Sheridan (1974)
has identified a continental margin fault off the shore of
New Jersey which is on-strike with the landward lineament
zone ("MF" in Figure 10). This fault coincides with a
topographic high which divides the Baltimore Canyon into two
distinct basins. A rectangular-shaped magnetic high
(Klitgord and Behrendt, 1977), with a magnitude of about 200
gammas, is abruptly terminated or offset in the same area
(Figure 10).

Finally, the linear trend of the Susquehana River in
southeast Pennsylvania may reflect an en echelon or related
segment of the lineament. Canich and Gold (1977) reported
that the Tyrone-Mt. Union lineament consists of two en
echelon segments in the Valley and Ridge. This offset,
however, was relatively small compared with the offset
developed between the lineament and Susquehanna River.

The evidence discussed above suggests that the Tyrone-
Mt. Union lineament extends from Lake Erie to beyond the
Atlantic coastline, a distance in excess of 600 km. The
lineament zone is linear or concave toward the north in
shape (possibly part of a great circle path) and its length,
persistence through a variety of geologic terrains, and
geophysical expression indicate a fracture zone penetrating
to the mantle or deeply into the crust.

The Everett-Bedford Lineament

The Everett-Bedford lineament (Parrish, 1978) consists
of two distinct segments (Figure 9). In the Valley and
Ridge it is defined by the Everett lineament (Gold et al.,
1973). This lineament is characterized by the alignment of
gaps, river valleys, and the termination of anticlinal
structures (Kowalik, 1975). A sequence of strike-slip
faults with apparent displacements of less than 4 km (Fauth,
1968), separating areas with different deformation styles
(Root, 1970; Root, 1973), is also identified in this zone.
These features are typical of "Gwinn-type" lineaments
(Gwinn, 1964) which are thought to be confined to the
sedimentary section.

Root and Hoskins (1977) suggested that the steep
magnetic gradient found south of Pittsburgh (Figures 2 and
9) defines the second component of the Everett-Bedford
lineament, a subsurface fracture zone in the Appalachian
Plateau. Several observations suggest that this feature is
not a continuation of the Everett lineament and is probably
genetically unrelated. Recently acquired gravity data show
that major gravity anomalies, including the Beaver Falls
low, Greensburg low, and Somerset high ("BF", "GR", and "SO"
in Figure 1) are disrupted and possibly offset along a zone
which coincides with the magnetic gradient near Pittsburgh
("M" in Figu 1) and which extends at least to the
Pennsylvania-Maryland state line, apparently terminating the
Everett lineament. In addition, the absence of geophysical

expression and the "Gwinn-type" characteristics of the
Everett lineament indicate that it is confined to the
sedimentary section.

The Pittsburgh-Washington Lineament

It is proposed in this paper that the magnetic
gradient observed in the Appalachian Plateau is part of a
distinct lineament, herein called the Pittsburgh-Washington
lineament, which trends subparallel to the Tyrone-Mt. Union
lineament near the cities of Pittsburgh and Washington, D.C.

Additional evidence for the existence of this
lineament may be cited. A zone of structural discontinuity,
along which folds are interrupted or terminated, has been
mapped by Wagner and Lytle (1976) in the Appalachian Plateau
of western Pennsylvania parallel to the lineament. Some
folds are also developed parallel to this zone. A 2-km wide
zone of incoherent reflectors near otherwise excellent
reflectors, indicative of structural discontinuity extending
to the Precambrian, was noted near Friedens, Pennsylvania
("F" in Figure 10), by Abriel (1978). Thrusts in the
Martinsburg shale terminate or change strike south of the
lineament in the same area while the Martinsburg is not
thrusted to the north (Parrish, 1978). This change of
structural style may indicate semi-independent movement of
sedimentary blocks along the lineament zone. The
discontinuity apparently controls the distribution of some
of the Upper Devonian oil and gas fields (Abriel, 1978).

Surface and subsurface faulting was postulated here by
Shaffner (1963) based on his observations of drag folding on
Chestnut Ridge. Finally, the Oriskany sandstone isopach map
reported by Abriel (1978) suggests a disruption in the
lineament zone here.

The southeastward extension of the Pittsburgh-
Washington lineament is indicated by surficial and
geophysical evidence. A linear segment of the Potomac River
valley (Figure 10) defines the lineament between Pittsburgh
and Washington, D.C. A plot of historical seismicity
(Bollinger, 1973) includes a concentration of epicenters
along the Potomac here. Magnetic patterns in the same area
(Zietz et al., 1980) include truncated anomalies and
indications of magnetic trends cutting across the regional
grain. Gravity maps which cover this area (e.g., Woollard
and Joesting, 1964) are constructed from sparse data but a
few anomalies, including the Martinsburg low ("MA" in Figure
1), are disturbed along this section of the Potomac River.

Further southeast, the lineament is proposed to extend
beneath the Putuxent river inlet of the Chesapeake Bay
(Figure 10) and project into the Norfolk fracture zone ("NF"
in Figure 10) inferred by Sheridan (1974). There are no
strong terminations or offsets of gravity and magnetic
anomalies in this region to suggest the existence of the
lineament. However, a map of crustal thickness prepared by
James et al. (1968, Figure 7) shows northwest-trending Moho
structures south of the lineament in this area (Moho depths

shown in Figure 10). The lineament is strongly defined in the Atlantic by the southern flank of the magnetic high (Klitgord and Behrendt, 1977) mentioned earlier in connection with the Tyrone-Mt. Union lineament (Figure 10). The Norfolk fracture zone may extend the lineament as much as 500 km offshore.

The northwest extension of the lineament may pass along the linear northwest flank of the prominent gravity high (Ohio Div. of Geol. Survey, 1956) centered over Wayne county, Ohio ("W" in Figure 10). A concentration of historical earthquake epicenters (York and Oliver, 1976) on-line with the lineament may extend it to the shore of Lake Erie.

The Pittsburgh-Washington lineament exhibits characteristics of a "Gwinn-type" lineament (Gwinn, 1964) and features indicative of deeper crustal fractures. It appears to be similar in nature to the Tyrone-Mt. Union lineament and extends from Lake Erie to beyond the Atlantic coast of Maryland and Virginia, a total distance greater than 800 km. Its existence is presently tentative, but hopefully more corroborating geological evidence will be uncovered in the future.

The Lake Erie-Maryland Crustal Block

The crustal fractures associated with the Tyrone-Mt. Union and Pittsburgh-Washington lineaments define a northwest-trending block approximately 140 km wide and

approximately 600 km in length. It is proposed that the region included between the lineaments be called the Lake Erie-Maryland crustal block.

Several lines of evidence indicate that the Lake Erie-Maryland block may be an independent crustal unit. As described earlier, the great length, linearity, persistence through different geological terrains, subparallel orientation, and strong geophysical expression of these lineaments indicate deep fracture zones, possibly penetrating the entire crust. Further, a plot of seismic delay times shown in Figure 11 (from Herrin, 1969), although based on scant data, does include positive delay times in a zone roughly coinciding with the Lake Erie-Maryland block. Herrin (1969) suggested that these delay times are developed along the upper portions of the ray paths from which the map was constructed. Possibly these data reflect a region of thickened crust.

Additional evidence may be cited. The conspicuous magnetic gradient marking the New York-Alabama lineament (King and Zietz, 1978) is disrupted or absent between the Pittsburgh-Washington and Tyrone-Mt. Union lineaments (Figure 2). In addition, the offset rectangular magnetic high, described earlier (Figure 10), suggests a block-like structure between the offshore extensions of the lineaments. Parrish (1978) has reviewed the lineaments mapped in western Pennsylvania. Most appear to be confined to the sedimentary section since they the are not strongly reflected in gravity
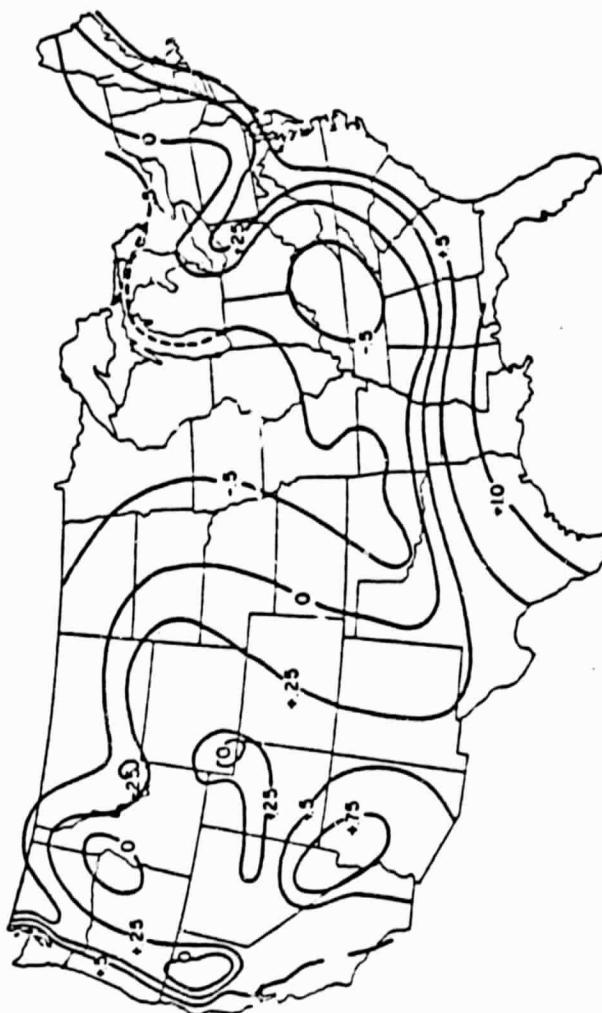
Figure 11. Seismic delay times in seconds (from Herrin, 1969) showing anomalous delay times in a zone roughly coincident with the Lake Erie-Maryland block.

and magnetic data. No indication of major displacements
along crustal fractures between the Tyrone-Mt. Union and
Pittsburgh-Washington lineaments is apparent. Thus, the
structures preserved within the Lake Erie-Maryland block
seem to be relatively undisturbed within the block and
interrupted along the deep crustal fractures beneath the
lineaments.

Offsets along the Bounding Lineaments

While it is not yet possible to present a geological
history of the Lake Erie-Maryland block, gravity and
magnetic data suggest major crustal displacements have
occurred along the bounding lineaments. Davis (1980)
reported that a comparison of northwest-trending magnetic
profiles constructed on opposite sides of the Tyrone-Mt.
Union lineament indicated about 60 km of right-lateral
displacement is preserved along the lineament. Similarly,
Muller et al. (1980) suggested that 60 km of right-lateral
offset along the Tyrone-Mt. Union lineament is indicated by
the disruption of the New York-Alabama lineament. The
configuration of the offshore magnetic high described
earlier (Figure 10) also suggests about 60 km of right-
lateral offset along the Tyrone-Mt. Union lineament. A
comparison of regional gravity patterns north and south of
the lineament may also indicate crustal offsets in excess of
100 km (Lavin, 1980).

Similarly, deflected isogals within the Beaver Falls

low, Greensburg low, and Somerset high ("BF", "GR", and "SO" in Figure 1), suggest about 50 km of left-lateral offset along the Pittsburgh-Washington lineament. In addition, Sykes (1978) reported a 50-km left-lateral offset of the magnetic high bounding the offshore extension of the lineament (Figure 10).

The Beaver Falls and Greensburg gravity lows were identified earlier (chapter 3) as probable sites for the northeast extension of the Rome trough. The offset suggested by these gravity anomalies is insufficient to resolve this ambiguity. However, the gravity patterns do indicate that the Rome trough, in either of these locations, has been displaced toward the west, north of the Pittsburgh-Washington lineament. Davis (1980) noted that the possible offset of Late Cambrian growth faults and apparent absence of displacement on a Lower Ordovician growth fault along the Tyrone-Mt. Union lineament indicate that offset occurred between Late Cambrian and Early Ordovician time. If the Rome trough is a Cambrian development, then its possible left-lateral offset along the Pittsburgh-Washington lineament would be Cambrian or younger in age. Perhaps the Lake Erie-Maryland block was offset as a coherent unit between Late Cambrian and Early Ordovician time.

Geological Nature of the Lake Erie-Maryland Block

Many of the structures described in this chapter are likely to be major tectonic boundaries. Sykes (1978)

proposed a tectonic model for intraplate regions including the Appalachian foldbelt. He suggested a genetic relationship between preexisting zones of weakness and major transform faults which were active during the opening of adjacent oceans. The possible association of the Tyrone-Mt. Union and Pittsburgh-Washington lineaments with oceanic transform faults, described earlier, and the subparallel orientation of the lineaments with respect to the direction of Atlantic seafloor spreading suggests that Sykes' model may apply to these lineaments.

The origin of these "preexisting zones of weakness" remains uncertain. Thomas (1977) proposed a sequence of rifts and transform faults defining the ancient Atlantic continental margin to explain the present geometry of the Appalachian chain. Subsequent continental collision(s) produced fold belts which conformed to the continental margin. Thomas' (1977, Figure 1) reconstruction suggests transform faults which are nearly on-strike with the Tyrone-Mt. Union and Pittsburgh-Washington lineaments. Perhaps the lineaments and the Lake Erie-Maryland block formed when a microcontinent, suggested by Thomas' reconstruction, was trapped between colliding continents forcing a westward displacement of the crust.

It is also possible that the crustal fractures associated with the lineaments developed as transform faults in the lower crust during Precambrian seafloor spreading. Subsequent deposition of the overlying eugeosyncline (Dietz

and Holden, 1966) and later reactivation of the transform faults produced the fracture zone now observed in the basement and sedimentary cover.

Rankin (1976) suggested that a triple junction formed near the gravity and magnetic highs over Newport, Pennsylvania ("NE" in Figures 1 and 2), during a Late Precambrian opening of the Atlantic ocean. The Scranton gravity high ("SC" in Figure 1) marks a rift zone which failed to reach the spreading stage while a second arm is preserved in the volcanic sequences of the Blue Ridge province according to this interpretation. Rankin (1976) suggested a northwest-trending failed trough for the third arm which could be related to the Tyrone-Mt. Union lineament and/or Lake Erie-Maryland block.

A final suggestion for an offset mechanism involves the Scranton gravity high ("SC" in Figure 1). The Scranton gravity high probably reflects a large dense block of mafic material penetrating much of the crust (Hawman, 1980) and appears to be terminated near the Tyrone-Mt. Union lineament. Perhaps this block acted as a buttress to deformation during Paleozoic continental collision(s). As the continental margin deformed, the relatively large inertia of the crust north of the Tyrone-Mt. Union lineament inhibited its displacement, resulting in further westward movement of the crust south of the lineament along a newly created or preexisting fracture zone.

CHAPTER V

SUMMARY OF RESULTS

Gravity and magnetic data reveal a number of crustal structures in southwestern Pennsylvania. A two-dimensional crustal model, consisting of three, constant density layers and constrained by available geophysical and geological data, showed that the major gravity anomalies in southwestern Pennsylvania could be attributed primarily to topographic relief along the top of the basement complex.

The top of the basement complex is not the gently eastward dipping surface commonly portrayed in previous studies. The prominent gravity low near Beaver Falls, Pennsylvania, is believed to be produced by a deep sedimentary basin which appears to have a maximum depth of about 8.5 km. The gravity low over Martinsburg, West Virginia, was modeled as a sedimentary basin of similar size and depth and is thought to mark a portion of the central Appalachian basin.

Other gravity anomalies could not be explained by basement sources alone. The narrow, but persistent, gravity anomaly near Chaneysville, Pennsylvania, is likely produced by tectonically thickened sediments associated with the Appalachian structural front. The prominent gravity high over Somerset, Pennsylvania, appears to involve a slight change in crustal thickness.

A correlation between the basement features described above and structures identified in previous studies exists. The Greensburg or Beaver Falls basement lows are probable sites for the northeast extension of the Rome trough. Mapped growth faults appear to be related to the basement highs and lows proposed in this study. Alternatively, the basement relief suggested here is the product of a series of faults in an extensive northeast-trending fault zone. An association of small basement highs and overlying sedimentary structures is indicated along the Appalachian and Intraplateau structural fronts. This association could indicate some involvement of basement rocks in the deformation of the overlying cover.

Geophysical and geological evidence was used in this study to extend the Tyrone-Mt. Union lineament in central Pennsylvania to beyond the Atlantic coast. A similar feature, the Pittsburgh-Washington lineament, was defined subparallel to this trend. These lineaments are probably expressions of fracture zones which penetrate deeply into the crust and possibly into the upper mantle. They may be old transform faults or fracture zones developed as part of a triple junction system. The Everett lineament seems to be an unrelated structure which is confined to the sedimentary section.

The crust beneath southwestern Pennsylvania and other Atlantic states has a block-like character. The Pittsburgh-Washington and extended Tyrone-Mt. Union lineaments enclose

a distinct crustal block over 100 km wide and greater than
600 km in length with the thickness of the crust. This
block, named the Lake Erie-Maryland block, has been
displaced, in one or more episodes, at least 50-60 km to the
northeast, probably during Upper Cambrian or Lower
Ordovician time, wih respect to the surrounding crust. This
structure is compatible with currently-held plate tectonic
models.

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ABSTRACT

A possible crustal block that passes through eastern Kentucky, proposed by a TVA study on tectonics in the southern Appalachians, was investigated using geophysical and geological information. The relation between the block and magnetic and gravity anomalies, seismicity, mineral occurrences, and deformation in the sedimentary section was examined, as well as the nature of the block and possible lateral offsets relative to the surrounding crust.

This study supports the existence of the block. The magnetic and gravity data show that the block is characterized by a low magnetic and gravity zone extending from southcentral Indiana to western Virginia. Numerous magnetic and gravity highs and lows are truncated by this zone. It is suggested that the crustal block underwent about 45 km of relative offset to the southeast during pre-Keweenawan times. It is also suggested that since the Precambrian the block has been reactivated during periods of tectonic stress, namely during the opening of the Proto-Atlantic, and the Taconic, Acadian, and Alleghenian orogenies. Movements during periods of reactivation are shown to be primarily minor vertical displacements.

The crustal block is shown to be, at present, relatively aseismic, although the poor documentation of seismicity in the eastern United States makes this

conclusion tentative. The boundaries of the block are shown
to be deep crustal fractures, possibly extending to the
upper mantle, along which mineral districts and occurrences
are likely to exist. Also the block is shown to have
influenced the deformation of the sedimentary cover. The
detailed nature of the block is shown to be characterized by
a deep crustal structure which results in the low magnetic
zone associated with the block. The nature of the structure
itself is unknown due to a lack of data from seismic
reflection and refraction surveys.

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CHAPTER I

INTRODUCTION

PURPOSE OF STUDY

Invest.gating the basement structure of the
Appalachians has many important benefits. Primary among
these is the relation of basement structures to oil, gas,
and mineral occurrences, and deformation in the overlying
sedimentary units. The recent interest in petroleum
resources in the eastern Overthrust Belt has renewed
interest in the deep sedimentary section and basement
complex of the Appalachians. In addition, the recent
emphasis on assessing seismic risks in the location of
nuclear reactors increases the importance of understanding
the relationship between basement structures and seismic
activity. Presently, few deep wells have penetrated the
basement in the Appalachians. Seismic reflection data have
been collected in some areas for the oil industry but these
are generally unavailable. However, gravity, magnetic, and
historical seismic data are available over much of the area
and are used here, along with geologic information, to
identify major crustal structures. The investigation of
crustal structures may also help in understanding the
evolution of the Appalachian mountain system, especially
the much debated role of the basement in the deformation of
the overlying sedimentary cover.

Various studies have demonstrated the presence of northwest trending crustal blocks in New York and Pennsylvania. The Tennessee Valley Authority (TVA) has also identified possible northwest trending crustal blocks in Kentucky and Tennessee. The purpose of this study is to investigate the crustal structure identified by the TVA in eastern Kentucky by using geophysical and geological data. Specifically, evidence will be presented that: 1) supports the existence of the crustal block, 2) indicates a relative lateral motion of the block, 3) extends the boundaries of the block, 4) more fully relates the block to seismicity, as well as mineralization, 5) shows an influence by the block on the deformation in the sedimentary section, and 6) suggests the nature of the block.

The remainder of Chapter 1 will discuss the general geology and tectonic history of the study area as well as previous studies which are important in the investigation of the crustal structure in the region. Chapter 2 will discuss the geophysical and geological characteristics of the proposed crustal block and its boundaries and will provide evidence indicating lateral motion relative to the surrounding crust as well as the age of the motion. In Chapter 3 the nature of the block will be considered as well as its relation to the tectonics in the area. The results of the study will be summarized in Chapter 4.

3

Location and General Geology

The primary study area is in eastern Kentucky (Figure
1). Also considered in this study will be a northwestern
extension into Ohio and Indiana and a southwestward
extension into Virginia, North Carolina, and portions of the
continental shelf.

The geological provinces in the study area are shown in
Figure 1. The Appalachian Plateau and Valley and Ridge
provinces are characterized by folded and faulted
sedimentary strata which extend from the Canadian Shield in
Ontario, Canada, to central Alabama, roughly paralleling the
eastern coastline (King, 1972). The relative intensity of
deformation divides this region into the less deformed
Appalachian Plateau province and the more deformed Valley
and Ridge province. These provinces overlie the Appalachian
Basin (Colton, 1964), an elongate and downwarped segment of
the earth's crust in which sediments have accumulated to
great thicknesses, possibly greater than 11 km (Bayley and
Muehlberger, 1968).

The Interior Lowlands, forming the vast central part of
the United States, is characterized by thin Paleozoic
deposits. However, basins and arches have formed in the
basement during at least Paleozoic times with sedimentary
thicknesses exceeding 3000 m in the deeper basins (King,
1977). Where the Cincinnati arch crosses through central
Kentucky (Figure 1), the sedimentary section thins to about
700 m. The lowlands grade eastward into the Appalachian

Plateau province as the basement deepens into the Appalachian Basin.

The study area is located mostly within the Appalachian Plateau province. The surface rocks of this province are mostly Pennsylvanian continental and coal-bearing strata which lie conformably above Mississippian and Devonian deposits (King, 1977). These rocks have been warped into a series of broad anticlines and synclines, but the deformation has been so slight that they appear nearly flat. The intensity of deformation typically decreases to the west.

The Valley and Ridge province is, in the study area and to the south, characterized by middle Paleozoic sedimentary rocks which have been deformed by closly spaced thrust faults. To the north of the study area the province exhibits mostly tight folding (King, 1977). The faults are initally developed as bedding plane thrusts which then break upward into higher stratigraphic units along moderate to high angle ramps (Harris, 1970). The Pine Mountain thrust sheet is a prominent feature of the province in this area. It was separated from the rocks beneath along zones of weakness in Upper and Lower Cambrian shales by compressional forces from the southeast (King, 1977). The thrust sheet has moved some 5-6 km to the northwest. The Valley and Ridge province is also known as the eastern Overthrust Belt, the part of the Appalachians characterized by the bedding plane faults and associated splay faults.

The Appalachian Plateau and Valley and Ridge provinces are separated by the Appalachian front (Price, 1931). The front marks the abrupt transition between the broad folding to the west and the more intense deformation to the east. Gwinn (1964) and Rodgers (1964) interpreted the front as the western limit of the large bedding plane thrusts of the Valley and Ridge.

The Blue Ridge province consists of more or less metamorphosed and highly folded Cambrian formations and Precambrian metamorphic and igneous rocks. These rocks have been thrust faulted to the west (Hatcher, 1978).

The Piedmont province is characterized by high grade metamorphic schists and gneisses and various plutonic rocks. (King, 1977). These rocks contain basement material and metasediments of Cambrian and late Precambrian ages.

The Blue Ridge and Piedmont Provinces are separated by the Brevard fault zone (Figure 1). The fault zone extends from central Alabama to western North Carolina and has been interpreted by King (1964, 1977) as a major strike slip fault. However, recent seismic reflection data (Cook, et al., 1979) suggest a thrust fault similar to the Pine Mountain thrust in which rocks from the east, in this case including large amounts of basement material, are thrust over thick sequences of sedimentary units. The data indicate that the eastern Overthrust Belt extends farther east and includes the Blue Ridge and Piedmont provinces. The Brevard fault zone is shown as a major splay fault off a

deeper fault plane (decollement) beneath the Blue Ridge and Piedmont provinces.

General Tectonic History

The first event that can be postulated to have taken place is the opening of a rift of Keweenawan age (1.12-1.14 by) through eastern Kentucky, Tennessee, Ohio, and Indiana (Keller, 1975; Keller et al., 1982). The rifting resulted in the generation of many of the mafic basement rocks found in the area (Rudman et al., 1965; Keller, 1982). The next event, the Grenville Orogeny, took place between 0.9-1.0 by (Stockwell, 1973). The orogeny was caused by a collision between the continents of America, Europe, and Africa (Young, 1980). The Grenville Province, which forms the eastern part of the Canadian Shield, is the metamorphic belt that was formed by this collision, the Grenville front being the westernmost limit of metamorphism. The front is exposed only in Canada.

The Grenville orogeny was followed by at least three distinct compressive orogenic episodes which occurred throughout the Paleozoic era. The Taconic orogeny , which took place throughout the Appalachians, was in the southern Appalachians a small but distinct Ordovician event (Rodgers, 1967). Uplift occurred to the east, probably over the Carolinas, which created a clastic wedge east of Tennessee. The wedge is composed entirely of Middle Ordovician sediments. The Acadian orogeny during the Middle to Upper

Devonian occurred primarily in the northern Appalachians and produced uplift which resulted in the formation of the Catskill delta. In the southern Appalachians the orogeny was limited to some tilting and erosion (Kummel, 1970). The Allegheny orogeny, essentially the last major compressive event to take place in the Appalachians, began during the Carboniferous and ended during the Permian. It has caused most of the deformation seen in the Appalachians today (Rodgers, 1967). The last major orogenic episode to take place in the study area was the tensional Palisade orogeny during the late Triassic (Kummel, 1970). This orogeny resulted in the formation of linear fault troughs, or basins, extending from Newfoundland to South Carolina, in which sedimentary and volcanic rocks have accumulated to more than 6000 m. Each subsiding trough had a fault on one side or the other and some had faults on both sides. These faults extend into the basement. Since the Allegheny orogeny the area has experienced several episodes of gentle arching with subsequent peneplanation.

The mechanism of folding and faulting in the Appalachians has been a matter of debate for decades. Two opposing views have been proposed to account for the deformation, the so called "thick-skinned" and "thin-skinned" theories. The thick-skinned school interprets the deformation in the sedimentary section as a reflection of basement deformations, resulting from basement folding or the vertical movement of basement blocks. The thin-skinned

school believes that the deformation is independent of the basement, the deformation resulting from the transport of thick slabs of sedimentary rock which are sheared off of underlying strata along decollement faults. The faults are developed in relatively incompetent Cambrian and Ordovician shales. The faults break upward into overlying strata along ramps causing the slabs to buckle, resulting in the folds expressed at the surface. Rodgers (1964) presents a good review of these hypotheses.

Recent geophysical and geological data indicate that a more intermediate view is likely. Hatcher (1978) suggested, from geological data, that the Blue Ridge and Piedmont provinces are complexes of sedimentary and basement rocks which have been brought to the surface along thrust faults which extend deep into the basement. He interprets the faults of the Valley and Ridge as extensions of the basement thrusts. A large COCORP seismic reflection survey (Cook, et al.,1979) in the southern Appalachians shows a large thrust sheet from 6 to 15 km in thickness which has transported crystalline basement rock over relatively undeformed lower Paleozoic sediments. The sheet extends from beneath the Valley and Ridge province to beneath the Coastal Plain with sediments involved in the Valley and Ridge and basement involved in the Blue Ridge and Piedmont provinces. The data suggest that the Blue Ridge and Piedmont provinces are allochthonous sections of the basement which have undergone at least 260 km of transport to the west.

Previous Studies

Recent studies have suggested that the Appalachian
mobile belt has undergone segmentation into distinct crustal
blocks which trend transverse to the belt (Seay, 1979;
Gableman, 1979; Diment, et al., 1980; Chaffin, 1981). The
boundaries of these blocks are lineaments which trend
northwest for many hundreds of kilometers (Figure 2). They
are recognized in satellite imagery and magnetic and gravity
data as breaks in trends and offsets of features. They are
often expressed locally by faulting, mineral occurrences,
igneous intrusions, and disruptions in the stratigraphy.
The lineaments have been interpreted as representing deep
fractures within the crust which extend down into the upper
mantle. The recognition of offset features suggests that
strike-slip motion has occurred. These features include
gravity and magnetic highs and lows as well as faults and
other structural features. According to the studies, the
crustal structure under the Appalachians consists of a
series of independent blocks each capable of motion relative
to the surrounding crust (Chaffin, 1981).

A major crustal feature that exists along the length of
the Appalachians, but does not follow the belts structural
trends, is the New York-Alabama Lineament. It extends in
nearly a straight line from Alabama to New York for some
1600 km. First described in its entirety by King and Zietz
(1978), it was recognized in aeromagnetic data as a series

of linear magnetic gradients facing either southeast or
northwest for nearly 1300 km (Figure 3). A lineament of
this magnitude and linearity is evidence of a profound
discontinuity in the crust. It suggests a boundary between
rocks of contrasting lithologies (Watkins, 1964). The
lineament occurs over the Appalachian Basin where,
unfortunately, the basement is covered by up to 10 km of
sedimentary rock (Bayley and Muehlberger, 1968), and is
unavailable for direct observation. The magnetic data
indicate that there is no vertical displacement of the
basement across the lineament (King and Zietz, 1978)

In gravity data the lineament is seen to be bordered to
the east by the broad gravity low associated with the
Appalachian Basin, except in Pennsylvania and New York where
part of the basin appears to be to the northwest. King and
Zietz (1978) used this association to extend the lineament
into central Alabama.

Seismically, King and Zietz (1978) state that the
lineament forms the eastern boundary of a relatively
aseismic band on maps of historical seismicity (Figure 4).
They interpret this band as representing a relatively stable
crustal block, its eastern boundary defined by the
lineament.

Tectonically, most of the strong deformation of the
Paleozoic rocks of the Appalachian Basin lies to the east of
the lineament. The folded rocks of the Baltimore salient
and the thrust faults of the Tennessee salient are

essentially tangential to the lineament. The lineament
seems to have acted as a limit to the deformation, the crust
to the west acting as a stable block against which the
deformation took place.

King and Zietz have advanced two possible
interpretations of the New York-Alabama Lineament. One is
that it represents a major strike-slip fault, resulting from
continental collision during the Grenville orogeny, similar
to strike-slip faults observed in the Tibetan Plateau
(Molnar and Tapponier, 1975;1977). The second suggests that
it is the expression of a deeply eroded suture zone.

The magnetic data used by King and Zietz (1978) shows
two significant gaps along the length of the lineament
(Figure 3). These occur in southern Pennsylvania and
eastern Kentucky. The possibility that these gaps may be
due to offsets of the lineaments caused by the lateral
movement of crustal blocks lead to the in-depth
investigation of crustal structure in Pennsylvania by
Chaffin (1981). His findings indicate the existence of a
crustal block over 100 km wide and possibly greater than 600
km in length which trends northwest across the gap (Figure
2). Geophysical and geological data indicate that the block
has been displaced at least 50-60 km to the northwest with
respect to the surrounding crust, carrying with it a section
of the New York-Alabama lineament. Most of the motion took
place during the Upper Cambrian or Lower Ordovician.

The TVA in 1979 published a study of tectonic provinces

in the southern Appalachians in which they attempted to
define zones of relatively high and low seismic activity
(Seay, 1979). The study incorporated historical seismicity,
gravity and magnetic data, and LANDSAT and SKYLAB photo-
imagery. The results of the study show that the southern
Appalachian region is crossed by three major discontinuities
observed in magnetic, gravity, seismic and photo-imagery
data (Figure 2). They are characterized mainly by the
truncation of major magnetic and gravity highs and lows.
They are interpreted as major lithologic and/or structural
boundaries that extend into the midcontinent and are used to
define tectonic provinces. One province identified by the
study, which is interpreted to be aseismic relative to the
surrounding crust, passes through eastern Kentucky and
corresponds well with the gap in the New York-Alabama
Lineament in eastern Kentucky. This association indicates
that the province may be a block structure which has
undergone lateral motion relative to the surrounding crust,
similar to that observed in Pennsylvania, resulting in the
observed gap.

In the study area itself, other important crustal
features have been identified in previous studies. The East
Continent Gravity High (ECGH) is a pronounced linear gravity
high trending northwest through Indiana and Ohio and then
north-south through central Kentucky and Tennessee (Figure
5). The maximum relief of the ECGH is in excess of 80
mgal., and the high is flanked on either side by gravity

lows. In the study area the ECGH is expressed magnetically by a broad magnetic high with superimposed high frequency anomalies (Figure 6).

Lidiak and Zietz (1976) interpreted part of the gravity and magnetic highs of the ECGH as an expression of the Grenville front. Bass (1960) and McCormic (1961) used well data in Ohio to extend the Grenville front southward from Canada. The position that they determined was noticed by Zietz, et al.,(1966) and Lidiak and Zietz (1976) to correspond to the western termination of the high frequency magnetic highs in Ohio. Based on this correlation Lidiak and Zietz (1976) extended the Grenville front through central Kentucky. More recently, however, Mayhew and Thomas (1980), Hawman (1980), and Keller, et al., (1982) modeled the ECGH as a buried rift of Keweenawan age. Their interpretation is based on the mafic lithology of the basement beneath the ECGH, the radiometric dating of rock samples, and computer modeling of the gravity and magnetic data. Seismic refraction profiles which cross the ECGH in central Kentucky and Tennessee (Warren, 1968) seems to support the rifting hypothesis. The data show a pronounced thickening of the lower crustal layer below the ECGH. This agrees with a model proposed by McGinnis (1970) and Hawman (1980) for a failed continental rift in which rifting results in the emplacement of mafic rocks within the lower part of the crust and basalts at the surface of the rift. The basalts cause the observed high frequency anomalies and

the deeper mafics result in the broad highs.

The Midcontinent Gravity High (MGH) is a horseshoe
shaped feature centered around the Great Lakes region
(Figure 5). It has a maximum relief of over 160 mgal. and
is flanked on both sides by gravity lows. Chase and Gilmer
(1973) interpreted the MGH as a failed rift of Keweenawan
age based on basement lithology, age, and gravity modeling.
Burke and Dewey (1973) have proposed that the high is the
expression of two arms of a triple junction centered under
Lake Superior, the third arm being less developed and
extending north into Canada. Keller, et al., (1982) suggest
that the ECGH is an extension of the eastern arm of the
triple junction.

The Rome Trough is a long graben-like feature extending
from eastern Kentucky through West Virginia (Figure 7). It
is well documented in eastern Kentucky where its northern
boundary is the Kentucky River Fault Zone. The basement is
downdropped to the south along a series of growth faults
(Webb, 1969) by as much as 3 km (Ammerman and Keller, 1979).
It is expressed in the gravity data as a low, but is less
well defined in the magnetic data. The thickening into the
Rome trough of the Middle Cambrian Rome formation (Thomas,
1960) shows that most of the faulting took place during the
Middle Cambrian. The trough has been extended through West
Virginia to the Pennsylvania border by Harris (1975) and
Chen, (1977) and into Pennsylvania by Chaffin (1981) as a
series of down-to-the-east growth faults.

CHAPTER II

GEOPHYSICAL AND GEOLOGICAL EVIDENCE

FOR THE CRUSTAL BLOCK

Introduction

This chapter will investigate the crustal block defined
by the TVA study in eastern Kentucky and surrounding states
using geophysical and geological data. The geophysical data
will include gravity and magnetic anomalies, and historical
seismic activity. Magnetic and gravity data are especially
important in the study of crustal structures since they
result directly from the anomalous structures at depth,
whereas surface geology is often only an indirect expression
of the structures, if the structures are revealed at all.
Magnetic anomalies are generally due to either changes in
the lithology of the basement or to changes in the depth to
the basement (Dobrin, 1976). Gravity anomalies also reflect
these changes but, in addition, are influenced by density
contrasts in the sedimentary cover. Both will also reveal
changes in the thickness of the crust and its various layers
(Zietz, et al., 1966).

After using geophysical data to further define the
crustal block indicated by the TVA study, geological data
will be investigated to see how well it supports the
geophysical data. This investigation will include patterns
of folding and faulting, stratigraphic disruptions, mineral

occurrences, and the occurrence of kimberlite intrusions.

Finally, the possibility that the proposed block may extend to the southeast beyond the study area will be considered.

Magnetic Evidence

The gap in the New York-Alabama Lineament in eastern Kentucky (Seay, 1979; Johnson, et al., 1980; Zietz and Gilbert, 1980) (Figures 3, 8) is a conspicuous feature of the lineament. To the northeast over West Virginia the lineament is characterized by a northwest facing gradient in the southern part of the state and a southeast facing gradient in the north. Both gradients represent a rise of between 400-600 gammas. Despite the reversing of polarity, the gradients form a remarkably straight line which extends undisturbed from southern Pennsylvania to the West Virginia-Kentucky border.

To the southwest of the gap the lineament is expressed as a southeast facing gradient of from 600-1000 gammas. This gradient also forms a straight line and extends from southeastern Kentucky to northeastern Alabama. It is directly on trend with the section of the lineament over West Virginia.

Between these two sections of the lineament lies the gap in eastern Kentucky. The gradients to the northeast and southwest are both abruptly truncated. The gap is approximately 90 km wide and is characterized by a

relatively low magnetic zone which extends northwest and terminates magnetic highs and lows to either side of the zone (Figure 8). The complex magnetic high associated with the East Continent Gravity High in central Kentucky (Keller, et al., 1982) is mainly to the south of this zone (Figure 6) and its high baselevel is truncated by the zone, although the high frequency anomalies continue across. Similarly, the high magnetic baselevel associated with the ECGH in Ohio is terminated by the low magnetic zone. Another major feature which is truncated by this zone is the elongate magnetic trough developed to the west of the New York-Alabama Lineament in West Virginia. Many other highs and lows can be seen in Figure 8 to terminate against the low magnetic zone. The lineaments which form the northeastern and southwestern boundaries of the low magnetic zone are here called the Cincinnati-Winston Lineament (C-W Lin.) and the Lexington-Charlotte Lineament (L-C Lin.), respectively.

In the southeast of the study area the low magnetic zone ends about 45 km past the New York-Alabama Lineament in western Virginia. The zone ends against a northeast trending linear magnetic high (Figure 8). The high has a maximum relief of about 700 gammas and parallels the New York-Alabama Lineament. The main section of the high is approximately 80-90 km in length, the same as the length of the gap.

To the northwest of the study area the data suggest that the low magnetic zone continues through northern

Kentucky, southern Ohio, and into southcentral Indiana. The
low continues to truncate magnetic highs and lows on either
side.

The magnetic data presented above supports the
existence of an anomalous crustal structure in eastern
Kentucky and surrounding states which trends roughly
northwest. It is approximately 90 km in width and extends
over 400 km from southcentral Indiana to at least western
Virginia. It is shown to be characterized by a low magnetic
zone. In light of previous studies outlining the block
structure of the crust beneath the Appalachians (Seay, 1979;
Gableman, 1979; Diment, et al., 1980; Chaffin, 1981), it is
considered likely that the crustal structure identified here
is a block similar to that described by Chaffin (1981) in
Pennsylvania. In both cases the structures are marked by a
gap in the New York-Alabama Lineament and terminate magnetic
highs and lows on either side. The boundaries of the block
indicated here are marked by the Cincinnati-Winston and
Lexington-Charlotte lineaments. The block apparently
extends across the Grenville front and ends in southcentral
Indiana against the Saint Lawrence-Mississippi Lineament
proposed by Gableman (1979) (Figure 8). This major
lineament is a system of smaller lineaments and deformation
loci which Gableman interprets as a major right-lateral
wrench fault which acts as the western terminus of many
Appalachian crustal segments discussed in the literature.
An extension of the block to the southeast is considered in

a later section.

Possible motion of the block relative to the surrounding crust may be determined by considering the linear magnetic high described in western Virginia (Figure 8). This high is of approximately the same magnitude as the New York-Alabama Lineament to the north and south and is about the same length as the gap in the lineament. It is therefore considered likely that the linear magnetic high is a section of the New York-Alabama Lineament which has been offset by about 45 km to the southeast either by motion of the crustal block itself or by a northwest motion of the surrounding crust. The bounding lineaments must therefore represent deep crustal fractures An examination of magnetic profiles across the linear magnetic high and across the New York-Alabama Lineament to the north and south (Figure 9) support the suggestion that the linear high is an offset section of the lineament. The general shape of the linear high (Profile B-B´) is the same as that of the New York-Alabama Lineament to the north (Profile A-A´) and to the south (Profile C-C´). All three are characterized by a sharp peak of about 800 gammas with a broad low to the southeast and a narrower low to the northwest. Further evidence of a relative southwestward lateral motion can be seen by a close examination of the magnetic data on Figure 8. A series of broad highs (marked H) and lows (marked L), roughly perpendicular to the block, are developed south of the block which terminate along the Lexington-Charlotte

Lineament. These apparently continue on the opposite side of the block, although the highs and lows there are less well developed. Within the block highs and lows of similar wavelength to those on either side are developed such that the highs within the block line up with the lows outside and visa versa. However, if the block is shifted back to its proposed original position the highs and lows line up reasonably well and are continuous across the block.

The Grenville Front is a structure which is apparently revealed in the magnetic data. A very prominent lineament exists in central Kentucky which trends approximately north-south (Figure 8). It is an elongate and narrow magnetic low to the west of the high frequency magnetic anomalies of the ECGH. This lineament is primarily to the south of the block and agrees well with the placement of the Grenville Front based on well data (Figure 15). Also it is approximately on trend with the Grenville Front in Ohio (Bass, 1960; McCormic, 1961; Keller, et al., 1982). Zietz et al., (1966) associated the Grenville Front with the termination of the high frequency anomalies to the west of the lineament. However, this may be fortuitous due to the currently accepted rifting origin for these anomalies. However, the front does agree well with the termination of the anomalies throughout the study area and may indicate that one had a controlling influence on the other.

The extension of the Grenville Front through central Kentucky is important in considering the age of the relative

block motion. The magnetic and well data show that the
Grenville Front crosses the block without offset. This
indicates that any lateral motion occurred before the
Grenville orogeny and that little motion, if any, has
occurred since.

Another line of evidence supports a pre-Grenville age
for the motion and pushes the age back even farther. The
ECGH, as previously shown, extends from northeastern
Tennessee into eastern Kentucky and then from southern Ohio
northwestward to southern Michigan (Figure 5). The age of
the ECGH, interpreted as a failed rift zone, is most likely
Keweenawan. This line of rifting shows four potential gaps
along its length, three of which are relatively small (less
than 30 km). The fourth is around 100 km wide and is
located in eastern Kentucky and occurs over the proposed
block. The gap is present in both the gravity and magnetic
data. In the magnetic data the gap occurs in the high
baselevel associated with the deeply emplaced mafic bodies
within the crust, but not in the high frequency anomalies
which result from the buried extrusive basalts near the
surface. This indicates that the block exerted a
controlling influence on the development of the rift zone,
inhibiting its formation across the block. Apparently,
enough rifting took place for basalts to be extruded at the
surface but not enough to emplace significant amounts of
mafic material in the lower crust. Moreover, since the high
frequency anomalies are not offset across the block, the

lateral motion which offset the New York-Alabama Lineament and the other highs and lows must have occurred before the rifting took place. The observed lateral motion must therefore be pre-Keweenawan in age. This suggests that the New York-Alabama Lineament is older than the Grenville age suggested by Ammerman and Keller (1979).

Gravity Evidence

The detailed gravity data in the study area (Figure 10) does not at first show any obvious indication of the crustal block suggested by the magnetic data. There appears to be no gravity low or high that corresponds with the observed low magnetic zone. Instead there are many individual highs and lows throughout the region of various sizes and shapes. The most important of these are the highs associated with the ECGH.

However, an examination of long-wavelength data shows some interesting trends (Figures 5, 15). Most notable is an apparent low gravity zone trending northwest through the study area in approximately the same location as the low magnetic zone. The superimposed boundaries of the proposed block show a good correlation with the low gravity zone. This correlation suggests a common cause and indicates a deep source.

Superimposing the boundaries of the proposed block onto the more detailed gravity map of Figure 10, many of the highs and lows can be seen to terminate against the

boundaries. The remaining highs and lows which cross over a boundary are all disrupted as they cross over and are terminated against the other boundary. There is no strong suggestion of any features being offset across the block.

The gravity features which terminate against the boundaries of the block include the Kentucky Gravity High (KGH), which is the southernmost portion of the ECGH, and a high to the north of the block which is another section of the ECGH. Features which are disrupted across a boundary include a pronounced 40 mgal low. Located just west of the KGH, this low becomes less distinct as it crosses over the Lexington-Charlotte Lineament and then increases again within the block and is terminated along the Cincinnati-Winston lineament. Also, where the gravity low associated with the Rome trough crosses over the Cincinnati-Winston Lineanent into West Virginia, the low abruptly increases in value by some 10 mgals, later apparently swinging north into eastern Ohio.

The gravity data supports the suggestion that any lateral motion took place before the Precambrian. Gravity data are more sensitive to variations in the basement depth than are magnetic data. Many of the observed anomalies can be attributed to arches and depositional basins which were developed on the basement during the Paleozoic. Since these anomalies show no offset features across the block, and since the magnetic data indicate that motion has taken place, the movement must have occurred during the

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Precambrian.

Historical Seismicity

The historical seismicity of the study area is an
important aspect to consider. It can be expected that a
crustal structure of the size proposed here should exert
some control over the seismicity of the region. The TVA
study, discussed in Chapter 1, indicated that the block is
relatively aseismic. The seismic map of the eastern United
States prepared by Hadley and Devine (1974) shows two
distinct bands of seismic activity oriented subparallel to
the Atlantic coastline (Figure 4). The western band shows
an apparent gap in seismic activity in southeastern Indiana.
This gap agrees well with a northwestern extension of the
proposed block.

The eastern seismic band shows little apparent change
across the block except perhaps for a lower density of
events. However, the TVA study of the eastern band of
activity did show a decrease in the frequency of events
across the block (Chapter 1). This is consistent with the
western seismic gap. The lack of a clear trend in the
eastern band may be due to activity within the eastern
Overthrust Belt which would not correlate with the deeper
structures considered here. These may partly mask any
effect of the block.

The recent Sharpsburg earthquake which occurred in
northcentral Kentucky on July 7, 1980 (triangle on Figure 4)

occured along the West Hickman fault zone (Figure 7) at a depth of around 12 km (Herrmann et al., 1982). The earthquake was the largest in the area in history, with an estimated body wave magnitude of 5.2. The fault plane was found to strike northeast and dip to the southeast. This is consistent with the West Hickman fault zone. The fault zone is associated with the southward extension of the Grenville front. Since faults are common along parts of the exposed Grenville front in Canada, this association indicates that the fault zone is the surface expression of basement faulting. This is supported by the 12 km epicentral depth determined for the earthquake, which is well within the basement. The direction of maximum stress in the area is compressional and is oriented approximately east-northeast (Zoback and Zoback, 1981) which makes the orientation of the West Hickman fault zone ideal for the relief of accumulated stress in the area. None of the other fault zones (Figure 7) are as favorably oriented. Therefore, the earthquake was most likely caused by the reactivation of the West Hickman fault zone.

The occurrence of the Sharpsburg earthquake in an area previously thought to be aseismic (between the eastern and western bands) highlights the insufficient documentation of historical seismic events in the eastern United States. Because of this problem, many gaps in the seismic activity which are now apparent in the data, such as those discussed above, may only reflect the generally poor knowledge of

seismicity in the area and may not be related to the actual
seismic activity. Therefore, any conclusions about
seismicity based on this data must be regarded as tentative.

The data presented above indicates that the block acts
as a relatively aseismic structure, as suggested by the TVA
study, except along old fault zones which may be reactivated
by the current stress regime.

Structure and Stratigraphy

The structural geology of eastern Kentucky is dominated
by two fault zones, each trending roughly east-west. They
are the Kentucky River fault zone and the Irvine-Paint Creek
fault zone (Figure 7) (McDowell, et al., 1981). A third
fault zone, the northeast trending West Hickman fault zone
occurs to the north. The Kentucky River fault zone and the
Irving-Paint Creek fault zone extend from the Cincinnati
Arch to the border with West Virginia. They are
characterized by a series of normal faults forming a graben
to the south, the Rome trough described in Chapter 1. The
fault zones intersect at the Cincinnati arch. The West
Hickman fault zone, a normal fault downdropped to the east
extends from this intersection to the border with Ohio along
the Grenville front.

These three fault zones are largely contained within
the boundaries of the proposed block. All three have their
northeastern termination along the Cincinnati-Winston
Lineament and their southeastern terminations near the

Lexington-Charlotte Lineament. Although the Rome trough extends into West Virginia (Harris, 1975; Chen, 1977), the surface expression of the growth faults do not.

A map of faults which have exhibited relatively recent motion (Cenozoic to present) in the United States (Howard, 1978) shows a normal fault along the Lexington-Charlotte Lineament (Figure 7). The fault, downthrown to the northeast, is the only recent fault mapped in eastern Kentucky or in any of the surrounding states although recent seismic events have occurred. This indicates that the block has been reactivated during relatively recent times to a degree sufficient to cause visible faulting at the surface.

Another fault that lies along the Lexington-Charlotte Lineament is the Elkhorn fault system in northcentral Kentucky (Figure 7). They are normal faults of post-Ordovician age which border downdropped basins (McDowell, et al., 1981).

Overall, the faulting seems to have been influenced by the block, although the relation is weak since they do extend somewhat beyond the southern boundary.

To the northeast of the proposed block are the gentle folds of the Appalachian Plateau. The folds trend northeast and extend undisturbed through West Virginia and end abruptly against the Cincinnati-Winston Lineament (Figure 7). The folding indicates that the block acted as a stable crustal section above which the Appalachian deformation was less intense than elsewhere. This indicates basement

involvement in the deformation of the overlying sedimentary section.

If the proposed block had exhibited any motion during the Paleozoic, it may have influenced the deposition of sediments during that time. The West Virginia Geological and Economic Survey has published stratigraphic maps (Chen, 1977) for the lower Paleozoic which cover a good portion of the study area. These include both thickness and lithofacies maps. Upper Paleozoic thickness and lithofacies maps were obtained from Oliver et al., (1967) and Rice et al., (1979). Formations younger than Pennsylvanian do not extend into the study area. The maps are, for the most part, based on widely scattered well data and stratigraphic projections. Therefore, the maps should be approached with caution. For convenience, areas of thick accumulations will be referred to as "basins" and areas of thin deposition will be referred to as "arches". These terms are used without any structural implications.

Thickness and lithofacies maps of formations in the Lower Cambrian show that the block apparently did not influence the deposition during that time. Sedimentation was resticted to an elongate geosyncline to the east which shows no distinct changes over the block. Middle Cambrian formations show some changes in trends across the block but these are generally small and may not be significant.

The most striking correlation of the stratigraphy with the proposed block occurs within the Conococheague formation

of the Upper Cambrian (Figure 11a). A deep basin (greater than 450 m) is developed over the block and trends at right angles to other well developed basins and arches to the north. The southern boundary of the basin is along the Lexington-Charlotte Lineament and the northern boundary correlates well with the Cincinnati-Winston Lineament. The lithology shows that dolomites over the block extend further to the northwest than elsewhere. Also, the thickness of clastics shows a distinct deepening over the block (not shown in the figure).

In the lower Ordovician, formations show disruptions of well developed basins and arches to the northeast as they pass over the block, but they still continue across it. However, the lithology does not show any firm correlation with the proposed block. The Middle Ordovician Chazy Group (Figure 11b) shows the striking truncation of a basin, developed to the northeast, against the Cincinnati-Winston Lineament. Again, the lithology shows little correlation with the block.

The Upper Ordovician to Lower Silurian formations show numerous disruptions across the block with basins and arches showing terminations against either the southern or northern boundary of the block, or showing disruptions across the boundaries.

Upper Silurian to Pennsylvanian formations show little correlation with the proposed block in either the thickness or the lithology.

The data presented above show that the stratigraphy
from the Cambrian to the Silurian show significant
disruptions where it crosses the proposed crustal block. In
many cases well developed basins and arches to the northeast
give way to numerous basins and arches over the block or are
truncated against the block. The most significant
disruptions occurred during Upper Cambrian and Ordovician
times. This suggests that the block exerted some sort of
influence over the deposition in the area due to
reactivations of the block during the lower Paleozoic. The
basins and arches suggest vertical motion. The lack of any
noticeable lateral offsets in the formations is consistent
with the idea that most of the lateral motion occurred in
Precambrian times as proposed earlier.

Mineral Occurrences

The central and eastern United States have numerous
occurrences of lead and zinc sulfides that have generally
been classified as Mississippi Valley Type (Figure 12).
Although they vary widely in regard to metal ratios, age of
host rock and age of mineralization, and structural traps,
these deposits share many of the same general
characteristics (Snyder, 1970). Mississippi Valley Type
deposits occur principally as hydrothermal replacement
bodies along faults in limestones and dolomites. These
deposits can occur at any depth depending only on the
thickness of the sedimentary section. Solutions carrying

the metals apparently dissolved the limestones and slowly deposited such minerals as galena and sphalerite. It has been shown from studies of fluid inclusions (Roedder, 1971, 1977) that the depositing solutions were brines with over 20% dissolved salts by weight and that the deposits were probably formed at between 70-100 C. These brines are generally believed to have migrated from depositional basins where the metals had been deposited during the course of normal sedimentation (Heyl, 1974). The brines moved laterally upward into structurally high areas where the metals were precipitated as ore minerals.

Two important questions concerning these deposits which have yet to be fully answered concern the source of the heat for the hydrothermal fluids, and the mechanism by which the brines migrate out of the basins. Skinner (1969) has shown that the deposits occur far from any obvious igneous activity. Snyder (1970) proposed that Mississippi Valley Type deposits were controlled by structural lineaments which represent profound breaks or discontinuities within the crust. The lineaments provide avenues for the escape into the upper crust of heat generated by magmas in the upper mantle. The rise in the geothermal gradient along an activated part of the lineament would initiate, by pressure differential, the migration of brines out of nearby sedimentary basins and into the heated areas. These zones may also have been the sites for deep-seated igneous intrusions.

This provides a basis for investigating the presence of deep crustal fractures by observing trends in mineralization. The Cincinnati-Winston and Lexington-Charlotte lineaments are assumed to be deep crustal fractures based on the geophysical evidence.

At the intersection of the Kentucky River fault zone, the Irvine-Paint creek fault zone, and the West Hickman fault zone occurs a large mineral district (Figure 13). The Central Kentucky Mineral District (Jolley and Heyl, 1964; Snyder, 1968) is a Mississippi Valley Type deposit which consists of deposits of barite, galena, sphalerite and flourite. The deposits of major importance occur as veins in faults and are of two main types· fissure fillings and breccia replacements. Jolley and Heyl concluded that the ores were deposited from rising heated solutions that used the major and minor fault systems in the area as channelways from deep-seated heat sources. They interpreted the veins as being epithermal or telethermal deposits.

The Central Kentucky Mineral District shows an important correlation with the proposed block. Figure 13 clearly shows a pronounced elongation of the district along the Lexington-Charlotte Lineament. Thus, it is likely that the lineament acted as a zone of weakness along which the heated solutions migrated, the actual sites of deposition being determined by the Elkhorn fault system. The age of the mineralization has not been determined rodiometrically and can only be stated as being post-Ordovician.

On closer examination the district shows several distinct zones of mineralization (Jolley and Heyl, 1964). Of the four largest zones in the district, two lie directly on the Lexington-Charlotte Lineament along with two smaller zones. This strongly indicates that the lineament had a controlling effect on the mineralization.

The general outline of the mineral district also shows another interesting trend of mineralization. The district shows a distinct pattern of occurrences including three of the four main zones of mineralization as well as several smaller zones along a line trending northeast along the proposed extension of the Grenville front, in this case expressed as the West Hickman fault zone. Faulting is also associated with the Grenville Front in parts of the Canadian Shield. The mineralization indicates that the front may have acted as a zone of weakness.

Two major Mississippi Valley Type mineral districts in western Virginia apparently correlate with the Cincinnati-Winston Lineament although the correlation is less distinct than in central Kentucky. These are the Austinville-Ivenhoe district and the Gossan district (Figure 12). They have their main trend aligned with the dominant trend of the Appalachians and not with the lineament.

The Austinville-Ivenhoe district consists of northeast trending veins of sphalerite, galena, and pyrite deposited in Lower to Middle Cambrian carbonates of the Blue Ridge Province (Brown and Weinberg, 1968). The mineralization is

post-Cambrian, but the exact age is unknown. As with other Mississippi Valley Type deposits it is interpreted as epigenetic, its minerals deposited by hydrothermal solutions rising through fault plumbing. The deposits occur as both fissure fillings and breccia replacements.

The Gossan district is characterized by northeast trending sulfide pods and lenses, mostly in the form of pyrrhotite with minor sphalerite, chalcopyrite and galena, in metamorphic rocks of the Blue Ridge province (Kinkel, 1967). The pods and lenses occur in shear zones developed in the country rocks. Kinkel (1967) interpreted the district as resulting from the hydrothermal emplacement of veins along pre-existing shear zones in the country rock. More recently, Henry and Craig (1979) have interpreted the mineralization as deriving from the syngenetic precipitation of pyrite from a submarine volcanic vent with subsequent deformation and metamorphism. The shear zones would strain during metamorphism, the pyrite rapidly loosing strength with increasung temperature. The age of the mineralization has been determined radiometrically by Kinkel et al., (1965) and Henry and Craig (1979) as being between 310-430 my.

The position of these districts over the Cincinnati-Winston Lineament indicate that the blocks had a controlling influence on the mineralization. This is supported by the relative isolation of the two districts (Figure 12). The northeasterly trend of mineralization is not inconsistent with Snyder's (1970) proposal. Were the lineaments to act

as a conduit for hydrothermal fluids, the specific

emplacements of the deposits would still be influenced by

the fault structures in the sedimentary section, which in

this case are due mostly to the Allegheny orogeny of the

upper Paleozoic. The correlation of the lineaments with the

districts supports the hydrothermal interpretation for the

Gossan district proposed by Kinkel (1967).

Other less major mineral deposits which do not classify

as major districts occur along the trends of both

lineaments. One cluster of deposits in Indiana occurs along

the trend of the Lexington-Charlotte Lineament (Figure 12)

and forms one of the most notable clusters of mineral

occurr ces in the United States (Heyl, 1968). This

strikingly linear grouping lies along the west side of the

crest of a northwest trending anticline flexure and along

the Mount Carmal fault that extends northwest across

Indiana. The minerals are interpreted as having been

deposited from hydrothermal brines which migrated from

bordering sedimentary basins to anticlines along the

available fault systems.

Other occurrences in eastern Kentucky can be seen to

lie near the Cincinnati-Winston Lineament. There are two

distinct occurrences of galena, sphalerite, barite and

flourite (Figure 12) (Heyl, 1972) which are located in an

area northeast of the Central Kentucky Mineral District.

This area is essentially free of significant mineral

deposits with the exception of these two.

All the mineral occurrences presented above, when taken together, support the earlier conclusions that the boundaries of the block represent deep crustal fractures. These fractures act as avenues for hydrothermal fluids as proposed by Snyder (1970).

Kimberlite Occurrences

Small igneous bodies of post-Precambrian age occur at numerous locations throughout the central and eastern United States (Brock and Heyl, 1961; Zartman, et al., 1967; Snyder, 1970). They range from Ordovician to late Cretaceous in age and indicate that intermittent intrusions have occurred in this region throughout post-Precambrian times (Zartman, et al., 1967). Most prominent in the cratonic regions are alkali intrusives, igneous rocks high in sodium and potassium and deficient in silica. It has long been believed that these rocks are derived from upper mantle magmas which, upon differentiation, intrude into the upper crust along deep-seated fractures (Brock and Heyl, 1961; Ringwood, 1969; Snyder, 1970).

Kimberlite is a type of alkali igneous rock; a mica peridotite composed of phenocrysts of olivine, garnet, pyroxene, ilmenite, and sometimes diamond and zircon, in a matrix of similar minerals. It generally occurs in brecciated rocks. Parrish (1978) suggests that kimberlites are intruded along crustal fracture zones, the brecciation due to movement along the fracture which then acts as a

conduit for the intrusion. Ringwood (1969) has suggested a source depth of at least 120 km due to the occurrence of diamonds.

Kimberlites occur infrequently in the Appalachians as shown in Figure 2. In eastern Kentucky, the Elliot County kimberlites occur as small exposures over an area of about one square mile. Zartman et al., (1967) radiometrically determined the age of the intrusions to be between 257-279 my. Hunt et al., (1971) concluded that the emplacement was tectonically controlled by deep-seated regional faults. He believed that the controlling structure was the Irvine-Paint Creek fault zone. However, the kimberlites are located some 30 km to the north of this zone. They are more likely associated with the Kentucky River fault zone which is located only 3 km to the south. Parrish and Lavin (1982) have proposed that the emplacement of kimberlites in Pennsylvania and New York were controlled by the intersection between the Paleozoic growth faults of the extension of the Rome trough and zones of fracturing between crustal blocks. The kimberlites of eastern Kentucky occur at the intersection of the Kentucky River fault zone (the northern boundary of the Rome trough) and the Cincinnati-Winston Lineament. This association further indicates that the lineament is a major crustal fracture.

Southeastward Extension

Although the low magnetic and gravity zone ends in

western Virginia, there is evidence that the block continues
to the southeast and may extend beneath the continental
shelf (Figure 14).

The Triassic basins of the Palisade orogeny show a
possible influence on their development by the proposed
block. The Danville basin trends northeast from central
Virginia into North Carolina and is terminated along the
extension of the Cincinnatti-Winston Lineament. Also, Cohee
(1961) shows a buried basin (dashed lines) in North Carolina
which is terminated along the extended northern boundary of
the block. The Deep River basin, which trends northeast
from northern South Carolina to northern North Carolina, is
truncated along the extension of the Lexington-Charlotte
Lineament. The truncation of these features suggests that
the block may extend into this region. It suggests a
passive role in the formation of the basins. That is, no
block motion or reactivation was involved as indicated by
the lack of faulting in the basins along the boundaries of
the block. The southeastward extension of the block is
further supported by fault structures in the area. The
Brevard fault zone, discussed earlier, terminates against
the extension of the Cincinnati-Winston Lineament (Bayley
and Muehlberger, 1968). Also, the Gold Hill fault occurs
almost entirely within the extension of the block. These
faults also suggest a passive role for the block. However,
a more active role is suggested by a cluster of strike-slip
faults in northwestern North Carolina. They offset thrust

faults and indicate that the Lexington-Charlotte Lineament may have exhibited right lateral motion at some time after the development of the thrusts during the Allegheny orogeny. However, they may be shallow faults not associated with crustal structures whereas the basins and the Brevard zone are believed to extend into the basement.

Barosh (1981) points out that pre-Cretaceous Mesozoic dikes change from primarily northwest trending dikes in the south to primarily north-south trending dikes in the north along a line that corresponds well with the Lexington-Charlotte Lineament.

The Cape Fear arch, is a broad arch developed in the basement. The arch, as shown by Bayley and Muehlberger (1968), correlates well with the southeastward extension of the block and indicates that the block forms a basement high in the area. Seismic reflection results show that the Cape Fear arch continues to the southeast under the continental shelf. This is also observed in aeromagnetic maps of the Atlantic coastal margin (Behrendt and Klitgord, 1979) which show a zone of relatively high frequency anomalies extending from the mapped arch to the continental shelf. The trend of this basement ridge also coincides with the topographic trend of the Blake Outer Ridge (Hersay, et al., 1959; Belding and Holland, 1970). Seismic investigations indicate that the Blake Outer Ridge is a sediment drift. Le Pichon and Fox (1971) postulate that the Cape Fear arch has deflected deep ocean currents and initiated the deposition

of the sedimentary ridge, as has been observed elsewhere.
The arch indicates that the proposed extension of the block
has been reactivated and uplifted, since the block is not
characterized by a basement high in the study area.

Finally, compilations of upper mantle velocities (Pn)
from seismic refraction surveys (Allenby, 1980) show an
elongate high velocity zone trending approximately northwest
which correlates well with the extension of the proposed
block and the Cape Fear arch.

The information presented above indicates that the
crustal block may continue from the end of the low magnetic
and gravity zone southeastward as far as the continental
shelf. However, much of the area along the extension has
been severely thrusted during the Allegheny orogeny. This
thrusting necessarily complicates the correlation of surface
features and geophysical patterns with the proposed block.
Only major features have been used here as evidence for the
extension, and the basins and the Cape Fear arch are
unaffected by the thrusting.

CHAPTER III

NATURE AND TECTONIC EVOLUTION

OF THE CRUSTAL BLOCK

Introduction

This chapter will consider the general nature of the
block and its tectonic history. The geophysical data have
indicated that the block is characterized by a general
magnetic low and possibly a gravity low. As noted
previously, this may be due to changes in the depth to the
basement, changes in the lithology, or changes in the
thickness of crustal layers. Both a gravity and magnetic
low can be explained by an increased basement depth for the
block, a less mafic composition, or a combination of both.
Geophysical and well data will be used to investigate the
depth and lithology of the basement. A general tectonic
history of the block will be developed by considering the
ages of events which have taken place along the boundaries,
such as mineralizations and intrusions, the inferred ages of
features that are offset by the block, and stratigraphic
disruptions. Mineralizations and intrusions along the
boundaries of the block indicate motion along the boundaries
at the times of emplacement. These events require deep
reaching crustal fractures as conduits for magmatic
intrusions, as described in Chapter 2, and unless the
fracture zones are active they will be sealed at depths

below about 25 km due to pressure within the earth.

Basement Depth

The depth to the basement in eastern Kentucky is complicated by the development of the Rome trough (Ammerman and Keller, 1979). The effect of the down-to-the-south faults which form the trough, as well as the more regional trends associated with basins and arches, must be separated from the data if any changes in the basement depth over the block are to be noticed.

Deep well data in the area are not plentiful, but enough exist to draw some general conclusions. A compilation of basement penetrating well data in part of the study area has been made by Weaver and McGuire (1977). Additional information was obtained from Thomas (1960), McCormic (1961), and Bayley and Muehlberger (1968). Wells in southern Ohio show a fairly uniform basement depth of around 700 m below sea level. Four wells to the south of these and presumably to the south of the block , yet north of the Rome trough, give a depth of around 1000 m. Few wells are located to the southwest of the block, and those that are are located within the deeper portion of the Appalachian Basin to the southeast and must be disregarded.

The apparent deepening of the basement by about 300 m which is evident across the northern boundary may be accounted for by the regional basement slope from the Cincinnati arch to the Appalachian Basin. Summerson (1962),

Harris (1975), and Chen (1977) have interpreted the depths
in this way. However, Woodward (1961), using some of the
same well data, indicates a fault to account for the drop.
This proposed fault is located near the Cincinnati-Winston
Lineament. Considering the scarcity of data, the former
interpretation seems the most reasonable.

The CompuDepth map prepared for the TVA study on the
southern Appalachians (Seay, 1979) crosses over the block in
western Virginia. Compudepth is a program which directly
inverts magnetic data to determine the boundaries and
magnetizations of the sources of anomalies (O'Brien, 1972).
The TVA map, which covers part of the study area shows the
depth to three successively deeper magnetic units. The
upper unit is generally very shallow (less than 3000 m) and
probably reflects mafic bodies within the sedimentary
section. The two deeper units show considersble faulting of
large sections, some being downfaulted as much as 1800 m.
No consistent deepening of the units within the block is
observed. A comparison of these depths with the basement
depth maps of Harris (1975) and Chen (1977) showed that
within the Appalachian Plateau, where the basement maps are
most accurate due to a lack of thrusting and better well
coverage, the deepest CompuDepth depths are consistently
several thousand feet shallower than the indicated basement
depths. At one well location the deepest CompuDepth depth
is several thousand feet less than the known basement depth.
This indicates that either the magnetic units identified by

the program all lie within the sedimentary section or that the program was inaccurate in locating basement sources.

Magnetic data (Johnson et al., 1980; Seay, 1979) is used in this study to obtain additional information on the basement depth. Rough depth to source determinations were made using the standard Maximum Slope method. This method relates the source depth of magnetic anomalies to the horizontal length of the straight-line portion of the sides of the anomaly. of proportionality between the slope and depth assumed as unity. This method yields a maximum depth for the source. Theoretical anomalies from buried sources with similar orientations and magnetic inclinations as those in the study area (Vaquier, et al., 1951) shows that a proportionality of 1.0 gives depths in good agreement with the theoretical depths if profiles are taken at right angles to the trend of linear anomalies. A cosine correction is shown to be accurate for profiles not at right angles to trends.

The results of this investigation showed no significant change in the basement depth between the block and the surrounding crust. The average depth was around 3.5 km. However, due to the inherent error in picking the straight line portion of the slopes, a change in depth of less than 1 km would probably not be resolved.

Basement Lithology

The lithology of the basement is complicated by the
Keweenawan rifting that has taken place. The mafic basement
rocks which are the result of this rifting must be avoided
when considering the possible differences in lithology
between the block and the surrounding basement.
Compilations of basement lithologies in parts of the study
area from deep well data have been made by Rudman et al..
(1965) and Keller. et al.. (1982). Additional information
was obtained from the studies of Bass (1960) and McCormic
(1961). Figure 15 shows the location of the wells and the
general basement lithology. In Ohio to the east of the
Grenville front and away from any obvious rifting the
basement is composed of granites and granite gneisses. Poor
well control to the southwest of the block leaves the
lithology there less certain but indicates felsic rocks.
Many wells have been drilled within the block and most of
these show granite gneiss compositions.

The data indicates no significant change in the
basement lithology between the block and the surrounding
crust. The basement in both cases is predominently a
granite gneiss.

Deep Crustal Source

The lack of a significant change in the basement depth
or the lithology suggests that the low magnetic and gravity
zone may be due to deep crustal structures which are not

expressed at the surface of the basement. The broad
character of both lows supports this suggestion. Profiles
across the magnetic low generally show a relatively gradual
decrease in intensity followed by a gradual rise (Figure 9).
The edges of the low are poorly defined in any single
profile, most likely due to the superposition of the higher
frequency anomalies, and only in map form can the boundaries
of the low be determined with accuracy. Zietz, et al.,
(1966) studied deep crustal structure by studying long-
wavelength magnetic anomalies. Anomalies with wavelengths
of between 1-8 km are attributed to near surface sources.
The small anomalies in the study area whose source depths
were estimated have wavelengths between 10-30 km and reflect
lithologic inhomogeneities near the basement surface or
somewhat deeper. Anomalies with wavelengths over 64 km are
attributed to lithologic changes within the lower crust.
The complexity of the magnetic low, as shown in Figure 8
makes the wavelength of the base level change from the highs
on either side difficult to determine. However, the data
suggest a wavelength of at least 65 km and probably greater.
This locates the source within the lower crust.

The possibility that the block may be the result of
transform faulting has been considered. Turcotte (1974) has
shown that most transform fault blocks are between 50-200 km
in width with a mean of 250 km. Since small blocks are hard
to detect, the mean will certainly decrease as new
information becomes available. The width of the proposed

block is consistent with the range of 50-200 km. However, the rifting event from which the block motion could have resulted is unknown. The Keweenawan rifting is the earliest known, but the block has been shown to be pre-Keweenawan. That earlier episodes of orogenesis occurred is shown by the Hudsonian and Kenoran foldbelts of the Canadian Shield, but whether there was any associated rifting is not known. In any event, a transform fault origin would not explain the associated low magnetic and gravity zones and, therefore, seems unlikely.

Exactly what may occur within the lower crust to cause the magnetic and gravity low cannot as yet be determined. The upper crust may thicken at the expense of the lower crust, or the properties of the lower crust may change resulting in a lower susceptibility and density. Magnetic and gravity modeling would have little meaning due to the lack of constraints on the structure of the crust, such as obtainable from seismic reflection surveys. Many geologically reasonable models could be propoesd and few could be rejected.

Tectonic History

The first motion of the block that can be determined occurred during pre-Keweenawan times as evidenced by the lateral offset of the New York-Alabama Lineament and the continuity of the anomalies associated with the Keweenawan rift across the block (Keller, 1982). Precisely when this

motion occurred cannot be determined due to the unknown age of the lineanent and the generally sketchy knowledge of Precambrian tectonics. The motion is not due to the rifting since the rift to the north and south of the block would result in an opposite sense of motion to that which is observed.

The stratigraphic data show major disruptions from the Upper Cambrian to the Upper Ordovician. This corresponds well with the opening of the Proto-Atlantic during the Cambrian and early Ordovician and the subsequent closing which resulted in the Taconic orogeny of the Middle Ordovician. The greatest disruption occurred during the Upper Cambrian in the Conococheague formation (Figure 9a) during the opening phase of the Proto-Atlantic. The weaker expression of the Taconic orogeny may be due to the fact that the orogeny was centered in the northern Appalachians.

Radiometric dating of muscovites from the mineral deposits in the Gossan district of Virginia yield ages between 310-340 my. Henry and Craig (1979) concluded that the mineralization dated from the Acadian orogeny. This indicates that the block was activated during that orogeny with deep-seated magmatic intrusions resulting in the hydrothermal deposition of the minerals as described in Chapter 2. The ages of mineralization for the other mineral districts discussed earlier are not available except for the observation that they occur in Paleozoic units and are therefore post-Cambrian.

Muscovites from the Elliot County kimberlites have
yielded ages of between 257-279 my (Zartman, et al., 1967).
This indicates that the block was reactivated during the
Alleghenian orogeny during the late Mississippian to early
Permian. The reactivation reopened the fractures at depth
providing the kimberlites an avenue along which to intrude.
Since the Allegheny orogeny there has been little evidence
of any motion or reactivation of the boundaries along the
block. The development of Triassic basins during the
Palisade orogeny indicate only a passive influence by the
block with no motion involved. Historical seismic data
(Figure 4) show that the boundaries currently exhibit small
motions. However, these are minor compared to the
previously described reactivations.

The nature of the reactivations during the Paleozoic is
in most cases difficult to determine. The stratigraphic
data suggest primarily vertical motions during the Cambrian
and Ordovician. The lack of any lateral offsets in the
Paleozoic formations shown by Chen (1977) indicates that no
major lateral motions took place. The absence of an offset
along the Deep River basin (Figure 4) shows that no lateral
motion has taken place along the Cincinnati-Winston
Lineament since the Palisade orogeny. However, minor
lateral motions could easily go unnoticed and would be just
as effective at reopening fracture zones. The data,
however, seem to favor vertical motions. This is also shown
by the recent work of Howard (1978) (Figure 7) which shows

vertical motion along the Lexington-Charlotte Lineament.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Considered together, the various lines of geophysical
and geological data support the existence of the crustal
block defined by the TVA and provide a good deal of
additional information concerning the block. Although any
one line of evidence is insufficient to support this
hypothesis, considered together the data present a strong
argument in its favor.

The magnetic data show a pronounced low magnetic zone,
about 90 km wide, extending from southcentral Indiana to
western Virginia which truncates major linear anomalies on
either side. An apparent offset of the New York-Alabama
Lineament indicates that the block has undergone a
southeastward lateral motion of around 45 km relative to the
surrounding crust. Other magnetic highs and lows also show
an offset of 45 km across the block. The gravity data show
that major anomalies truncate against the block or are
significantly disrupted across the block boundaries.
However, no offsets of the gravity features are noticed
across the blocks. Also, a long-wavelength low gravity zone
corresponds well with the position of the low magnetic zone,
only it is less distinct. The relative lateral motion of
the block must have occurred during pre-Keweenawan times
since the gravity and magnetic signatures of the Keweenawan

rifting in the study area are not offset across the block. The seismic data show that the area postulated for the block is currently aseismic relative to the surrounding crust, except along old zones of weakness which may undergo reactivation due to the current stress regime. However, the occurance of the Sharpsburg earthquake in a zone previously considered aseismic highlights the fact that seismicity in the eastern United States is as yet poorly documented and that many aseismic zones apparent in the present data may not reflect actual seismic activity.

The block has had an influence on the development of folding and faulting in lower Paleozoic sediments. The Kentucky River, Irvine-Paint Creek, and West Hickmann fault zones occur over the block and extend only a little beyond the boundaries. Also, a belt of broad folding in the Appalachian Basin over West Virginia is abruptly terminated against the block.

Mineral occurrences and kimberlite intrusions correlate well with the boundaries of the proposed block. The Central Kentucky Mineral District occurs along the Lexington-Charlotte Lineament, and the Austinville-Ivenhoe and Gossan districts occur along the Cincinnati-Winston Lineament. Other less major occurrences also correlate with the boundaries. The Elliot County kimberlites occur along the Cincinnati-Winston Lineament. The theories for the formation of these mineral districts and kimberlites require deep crustal fractures.

The observed offsets and mineral and kimberlite occurrences along the boundaries of the block suggest that the Lexington-Charlotte and Cincinnati-Winston lineaments are deep crustal fractures which most likely extend down into the upper mantle.

The geological evidence also shows that the block has been reactivated at times since the Precambrian and that the reactivations correlate with the major tectonic episodes that have occurred in the study area. Stratigraphic disruptions show a peak during the opening of the Proto-Atlantic and the Taconic orogeny. Mineralization in the Gossan district correlates with the Acadian orogeny and the Elliot County kimberlites were probably intruded during the Alleghenian orogeny. All these occurrences indicate reactivations of the block during periods of regional tension and compression. Whereas the major pre-Keweenawan motion was lateral, the later reactivations were apparently mostly vertical. This is shown by normal faulting along parts of the Lexington-Charlotte Lineament and basins and arches in the stratigraphy. This does not, however, rule out some minor strike slip motion. Basement depth determinations based on well data and magnetic data show that the vertical motion was relatively minor since no change was found between the block and the surrounding crust.

The block has been extended northwest into central Indiana by aeromagnetic data and possibly to the border of

Illinois based on the linear zone of mineralization in Indiana which correlates with the southern boundary of the block. Geological data suggest a southeastward extension to the continental shelf.

This study has important implications in the area of mineral exploration. The boundaries of the block, being deep crustal fractures, are ideal sites for mineralization, especially Mississippi Valley type deposits. It may prove profitable to direct future exploration along the lineaments which form the boundaries in areas where deposits have not yet been found, especially along the Cincinnati-Winston Lineament.

This study also sheds some light on the "thick-skinned"-"thin-skinned" controversy concerning the tectonics of the Appalachians. The influence that the block has had on folding and faulting shows that the crust can play an important role in deformation, this being contrary to the widely accepted thin-skinned hypothesis. Primarily, the block has apparently inhibited the development of folds in the Appalachian Plateau province which are well developed to the northeast in West Virginia. Also, some faults are associated with the boundaries of the block, and the Kentucky River, Irving-Paint Creek, and West Hickmann fault zones occur primarily within the block. Increasingly, studies are showing that a view intermediate to the "thick-skinned" and "thin-skinned" ideas is more appropriate than either one.

The observations made concerning the age of the block also shed light on a controversy concerning the nature of the Grenville Province. The more traditional school of thought is that the province is a metamorphic belt resulting from the Grenville orogeny. Another idea which has been proposed is that the province is foreign to North America but was added during the Grenville orogeny (Irving, et al., 1974. Fahrig, et al., 1974). Baer (1977) suggests that the Grenville front is a major strike-slip fault with right lateral offset. Young (1981) disagrees with these hypothesis and points to the continuation of Proterozic rocks of the Labrador trough into the province. The crustal block proposed in this study , determined to be pre-Keweenawan in age, also continues into the Grenville Province and therefore supports the traditional view. The lack of offsets of the block and the Labrador trough across the Grenville front discounts the strike-slip theory for the front.

This study supports the conclusion of the TVA study that the crustal block is at present relatively aseismic, although with some reservation due to the poor documentation of seismic activity in the eastern United states. These associations are important in projects which need to assess seismic risks in the southern Appalachians.

This study compliments those of Diment, et al., (1980) and Chaffin (1981). It indicates that the basement in the Appalachians is segmented into a series of blocks, each

around 100 km in width and trending northwest, along much of the length of the belt. The relation of the blocks to seismicity and mineral occurrences and the information they provide concerning the role of the basement in tectonic deformation warrants the study of other possible block structures and the re-evaluation of those already described as new data become available. The recently published filtered gravity map of the United States (Kerr, 1982) shows many possible crustal blocks based on the terminations and offsets of linear highs and lows. Figure 16 shows the blocks already studied and indicates several others. Future studies of these blocks may advance the overall understanding of Appalachian crustal structure.

Altogether, several major conclusions can be made based on the geophysical and geological data. They are:

1) A major crustal block exists in eastern Kentucky and surrounding states, supporting the TVA study.

2) The block is about 90 km wide and is bounded on the northeast by the Cincinnati-Winston Lineament and on the southwest by the Lexington-Charlotte Lineament.

3) The boundaries of the block represent deep crustal fractures and are associated with significant mineral deposits.

4) The block has moved about 45 km to the southeast relative to the surrounding crust.

5) The block extends over 400 km from southcentral

Indiana to at least western Virginia and possibly
another 900 km to the continental shelf.

6) The block exhibited most of its relative
lateral movement in pre-Keweenawan times.

7) The block has been reactivated since the
Precambrian, especially during the Taconic, Acadian,
and Allegheny orogenies.

8) The movement during reactivations has been
primarily small scale vertical motions.

9) The structure responsible for the low magnetic
and gravity zone is probably located deep within
the crust and is not due to changes in basememt
depths or lithologies.

10) The cause of the relative lateral offset is
unknown but may be due to transform faulting during
an ancient rifting episode.
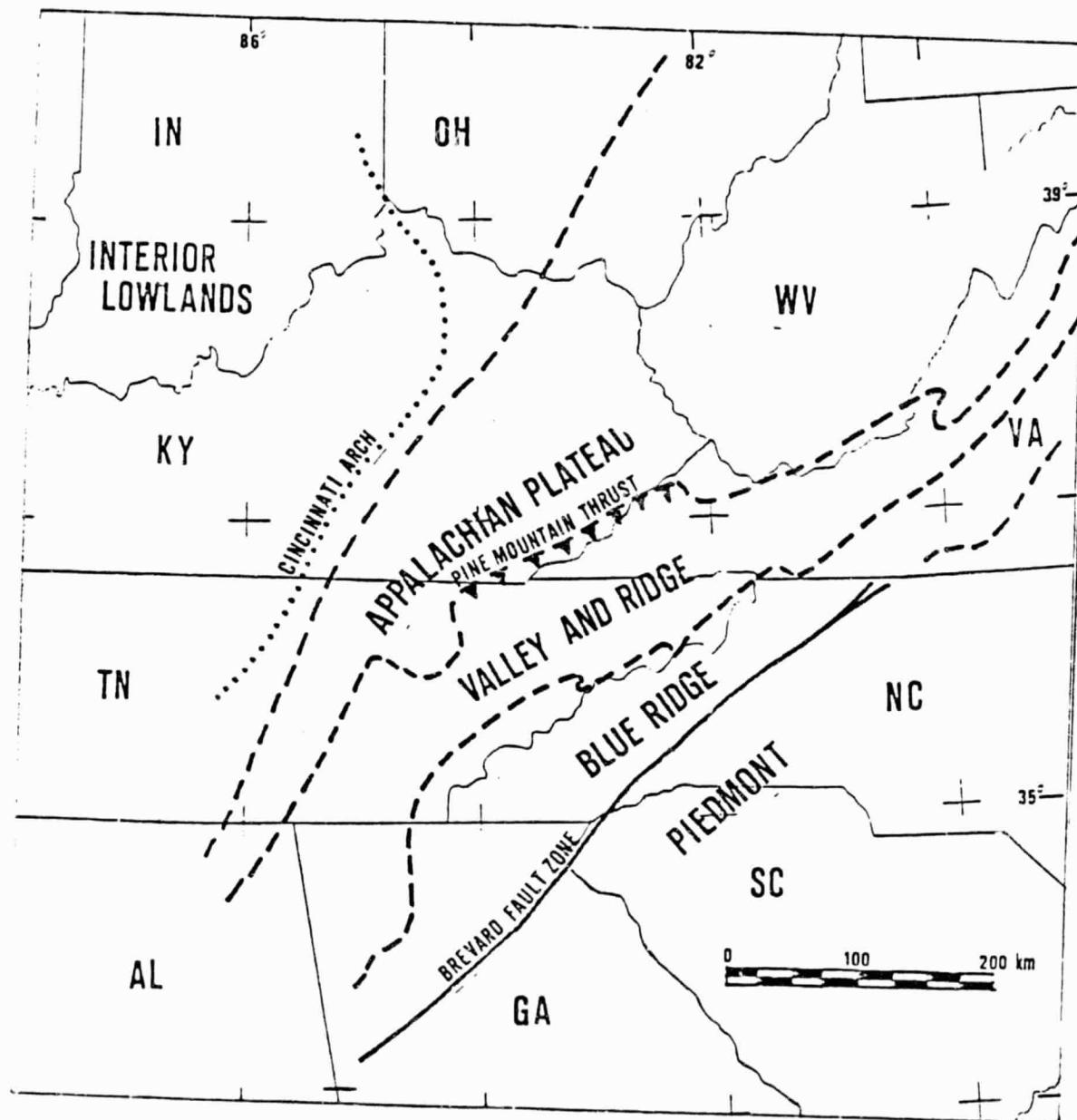
Figure 1
Outline of geological provinces and major structural
features in the study area.

Figure 2
Location of possible crustal blocks and known kimberlite
intrusions in the Appalachians. Rome trough is also shown.
Block boundaries from Seay (1979) (dotted lines),
Diment et al., (1980) (dashed lines), and
Chaffin (1981) (solid lines).

Kimberlites
1) Ithaca, NY
2) Dixonville, PA
3) Masontown, PA
4) Rockbridge County, VA
5) Elliot County, KY
6) Norris Lake, TN
7) Clear Springs, MD
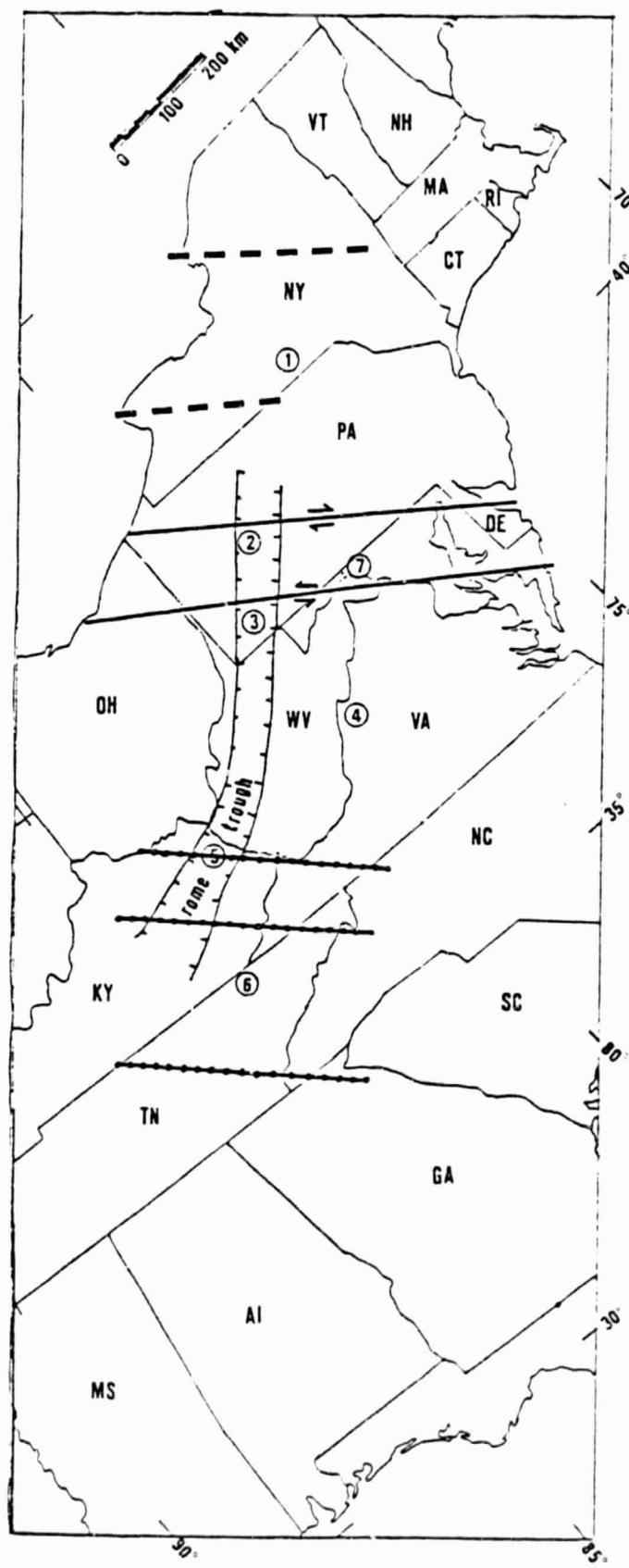
Figure 3
Aeromagnetic map showing New York-Alabama Lineament
(heavy dashed lines). From King and Zietz (1978).
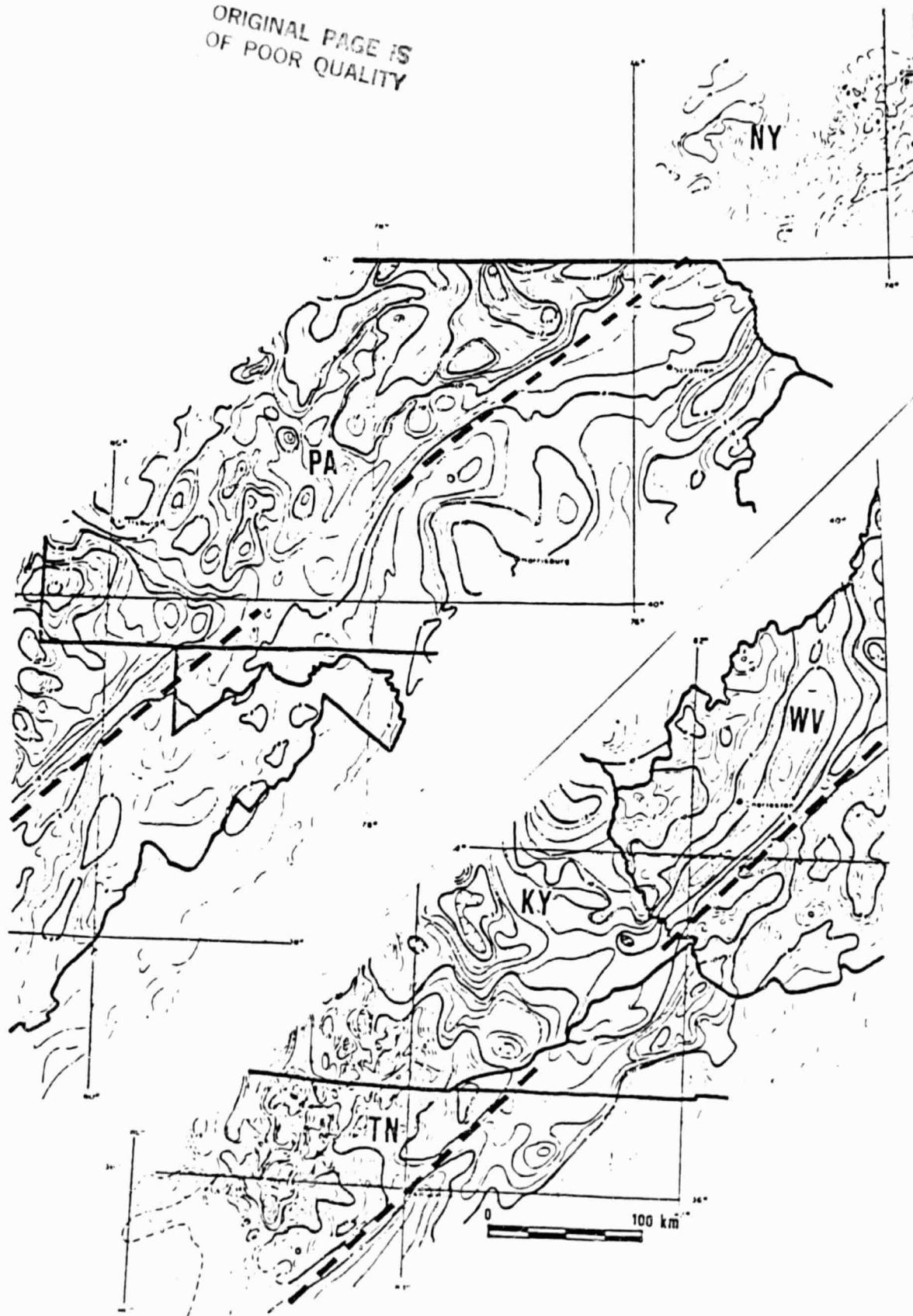
Figure 4
Seismotectonic map of eastern United States showing earthquake
epicenters of modified Mercalli III or greater, recorded from
1800 to 1972. Contours show number of epicenters per 10,000 km.
Location of New York-Alabama Lineament is based on magnetic and
gravity data. Dashed lines show boundaries of the proposed
crustal block. Contour interval = 4. Modified
from Hadley and Devine (1974).
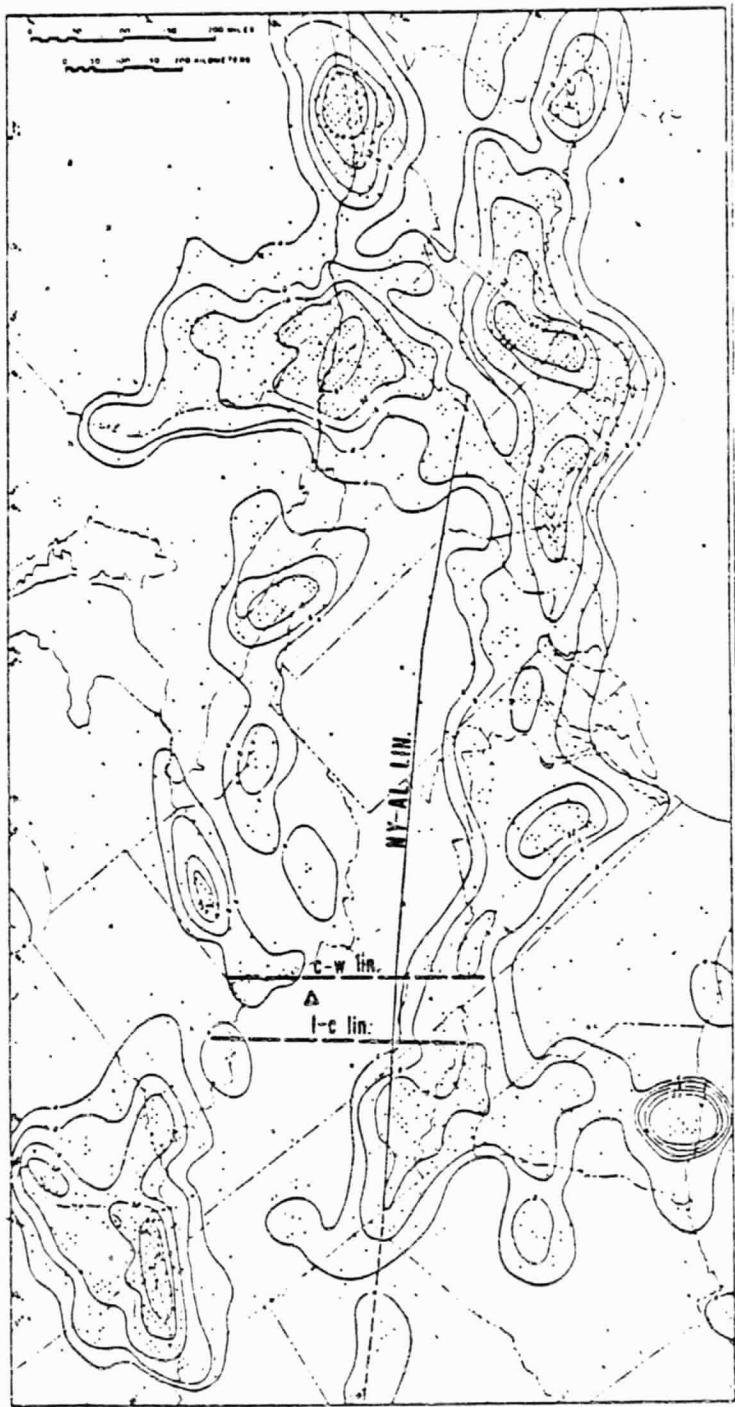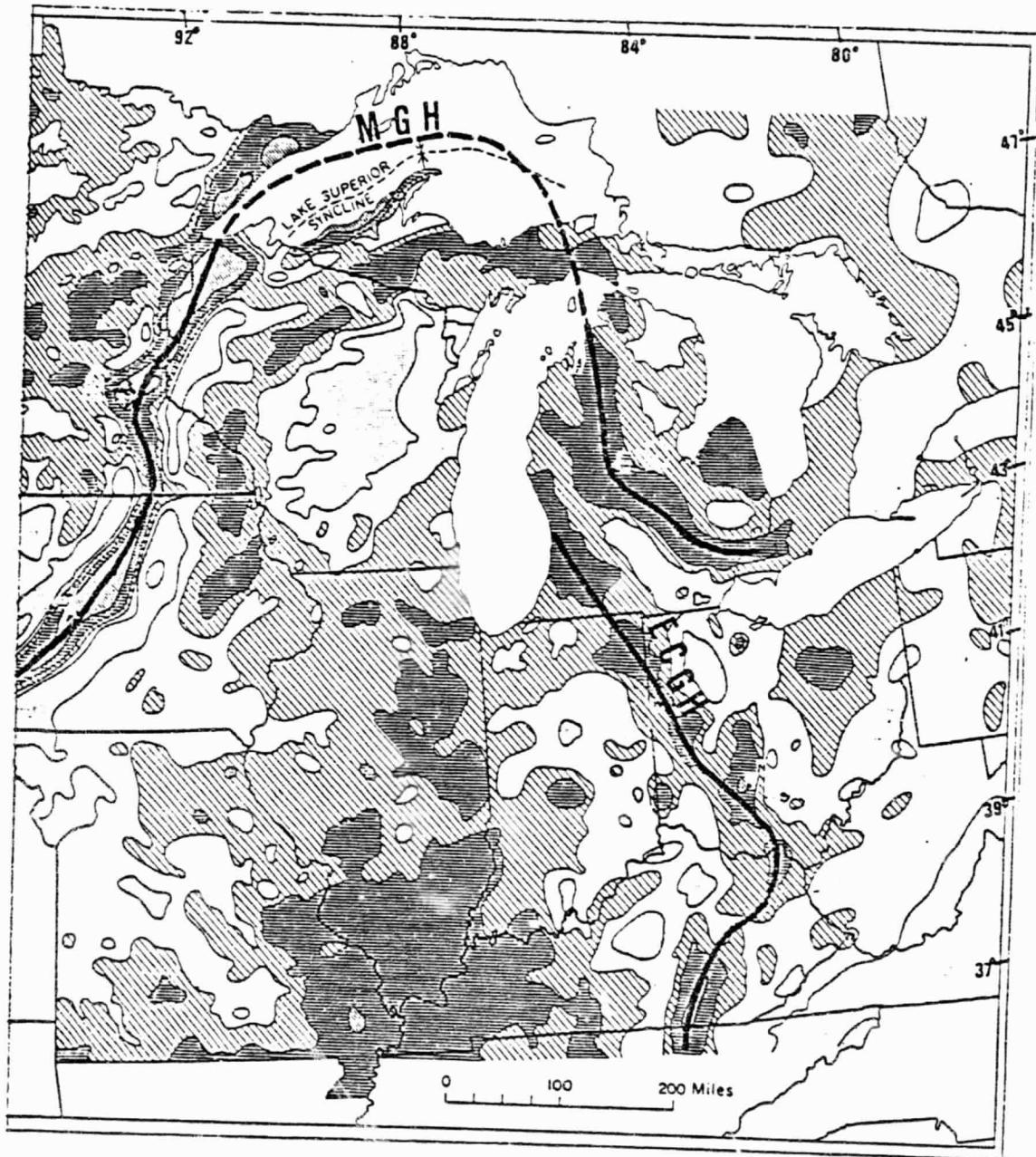
Figure 5
Bouguer gravity anomaly map of eastern United States showing
relation between the Midcontinent Gravity High (MGH)
and the East Continent Gravity High (ECGH).
Modified from Rudman (1965).

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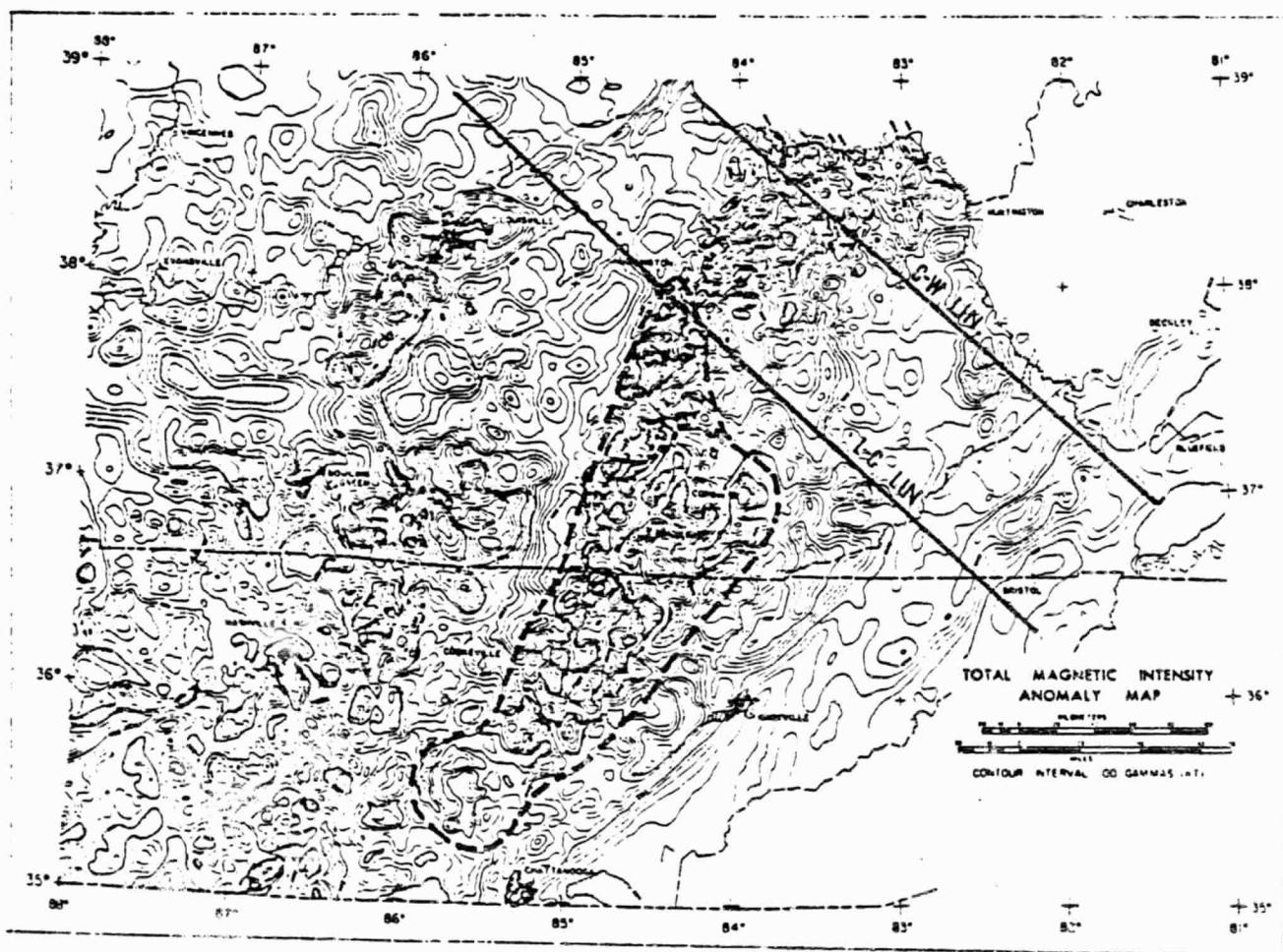
Figure 6
Total magnetic intensity anomaly map showing magnetic expression
of the ECGH in the study area. Dashed line marks boundary
of the Kentucky Gravity High. Solid lines show block boundaries.
Modified from Keller et al., (1982).
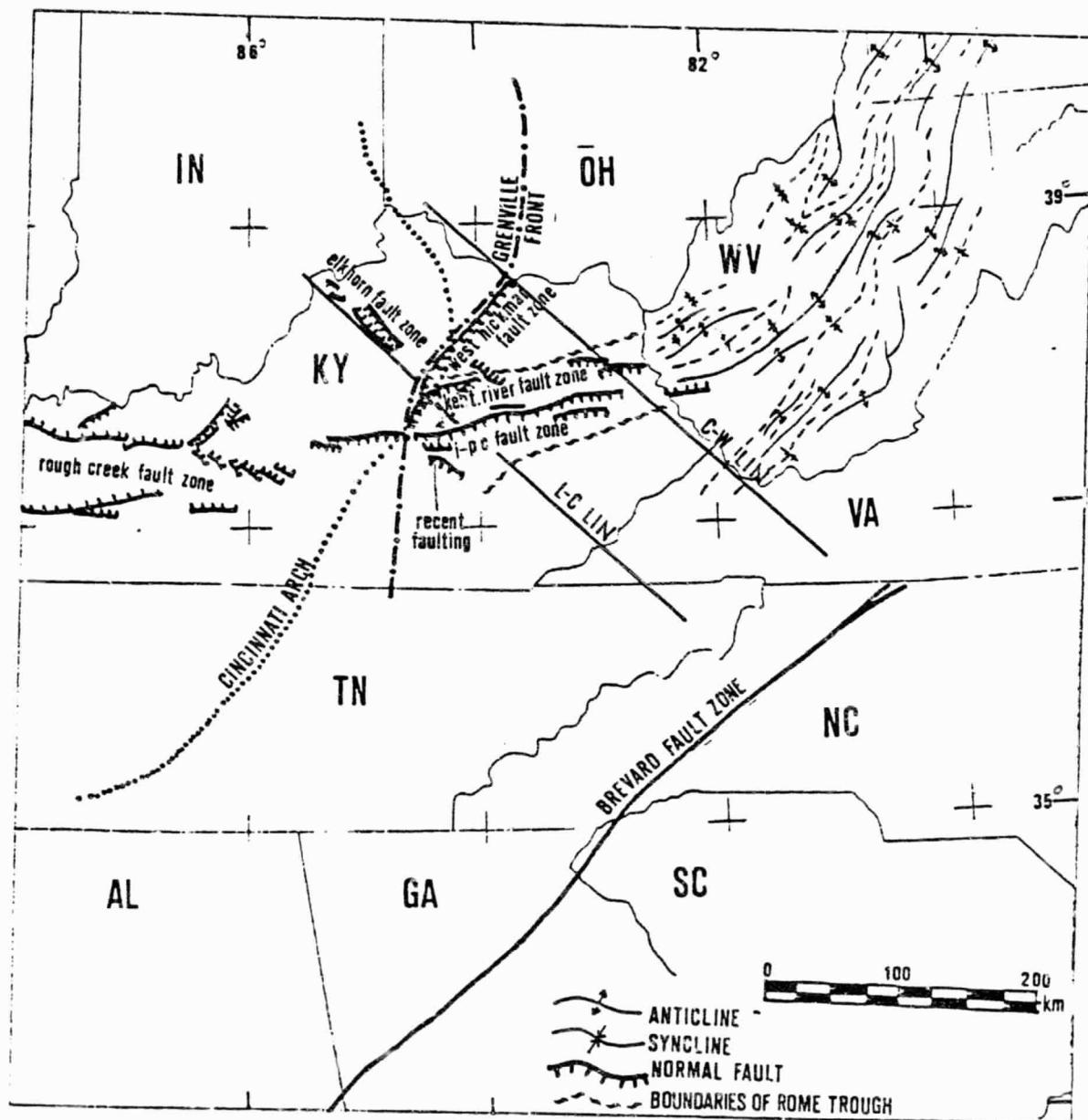
Figure 7
Important structural features in the study area. Thin solid
lines show boundaries of the proposed crustal block.
compiled from Cohee (1961), Bayley and Muehlberger (1968),
and McDowell et al., (1981).

Figure 8
Total magnetic intensity anomaly map of study area with major
features noted. H=areas of high intensity.
L=areas of low intensity. Modified
from Zietz (1981).

CONTOUR INTERVAL 200 GAMMAS

> 800 GAMMAS

< 600 GAMMAS
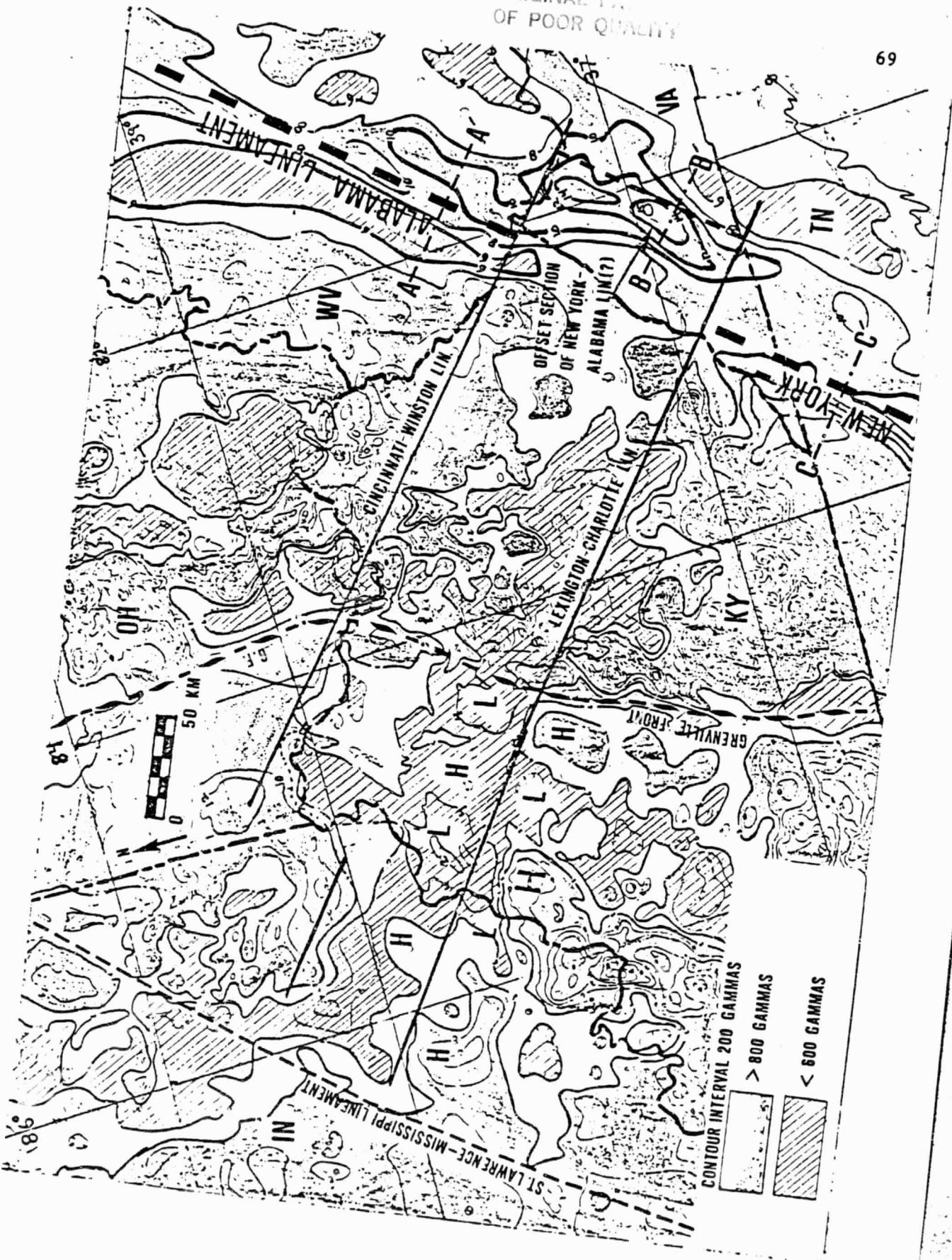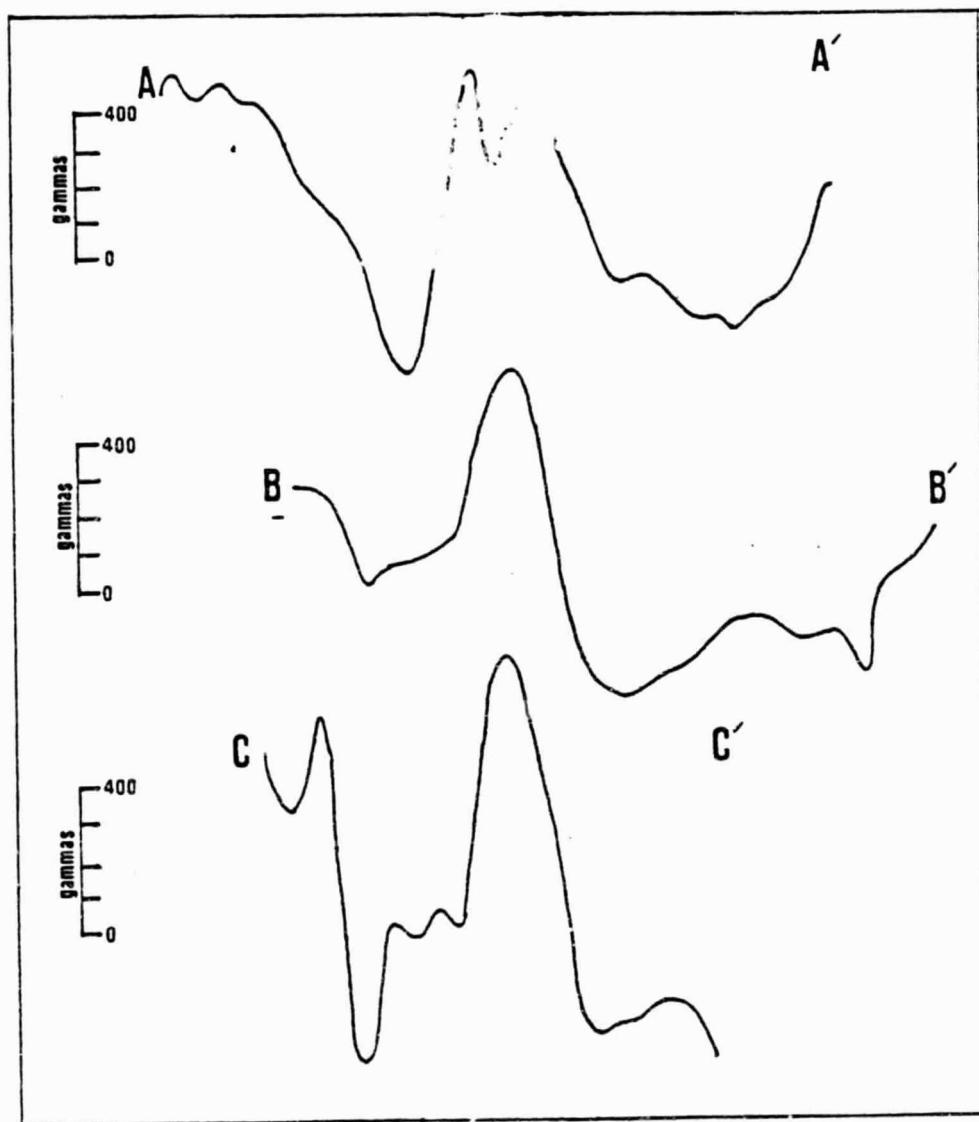
Figure 9
Comparison of magnetic profiles of the New York-Alabama
Lineament (along profile A-A´, along
profile C-C´) and its proposed offset
(along profile B-B´). Profiles
are located on Figure 8. Data from
Geological Survey (1978),
Johnson et al., (1980),
and Seay (1979).

Figure 10
Detailed gravity map showing boundaries of proposed crustal
block. Modified from Seay (1979).
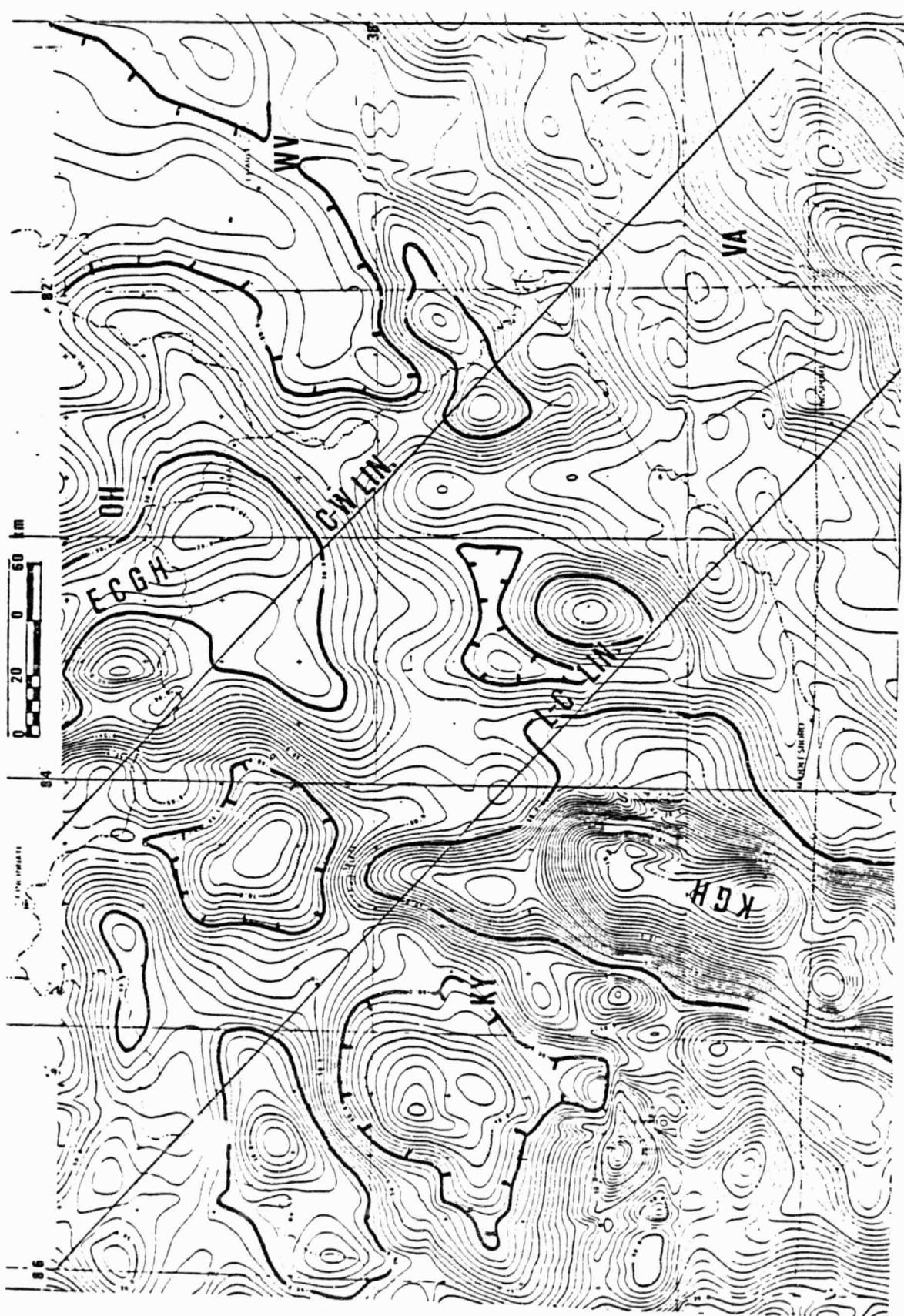
Figure 11
Stratigraphic thickness maps for the Upper Cambrian Conococheague
formation and Middle Ordovician Chazy formation.
Dashed lines show the boundaries of the proposed crustal block.
Modified from Chen (1977).

CONOCOCHEAGUE THICKNESS AND LITHOFACIES

CHAZY THICKNESS AND LITHOFACIES
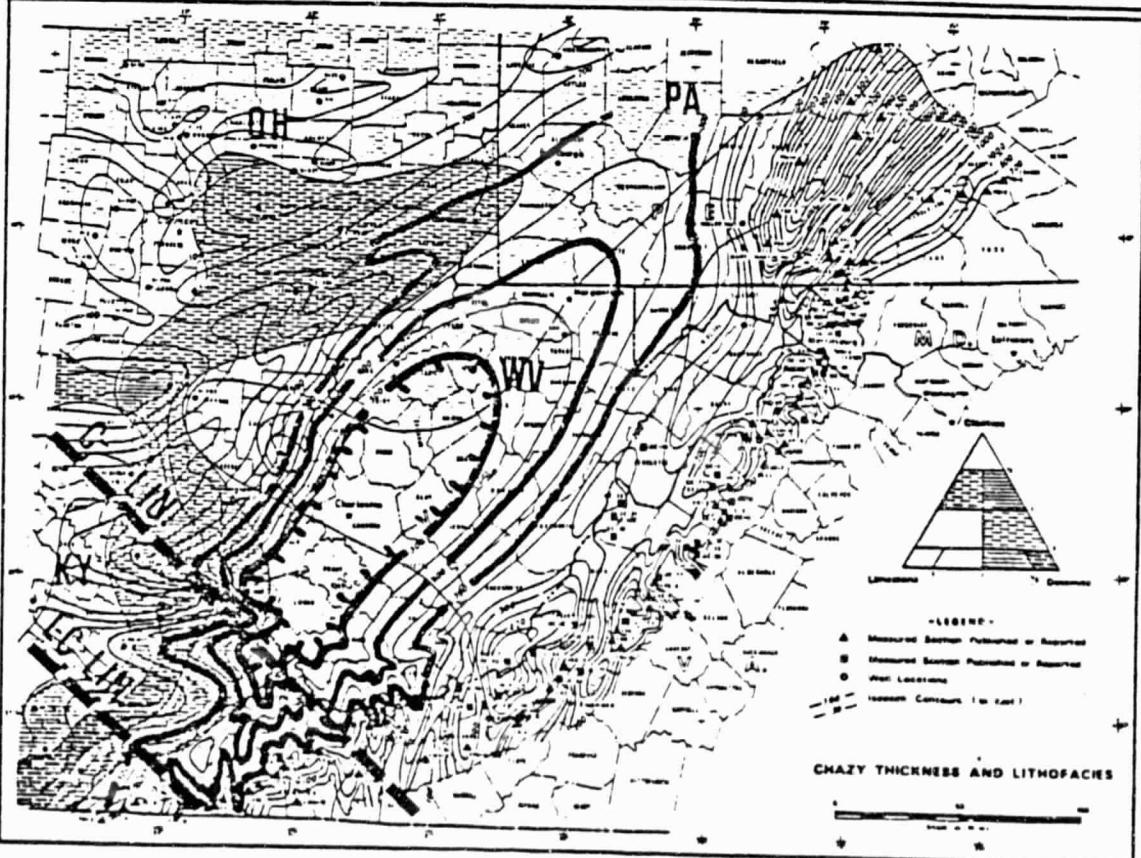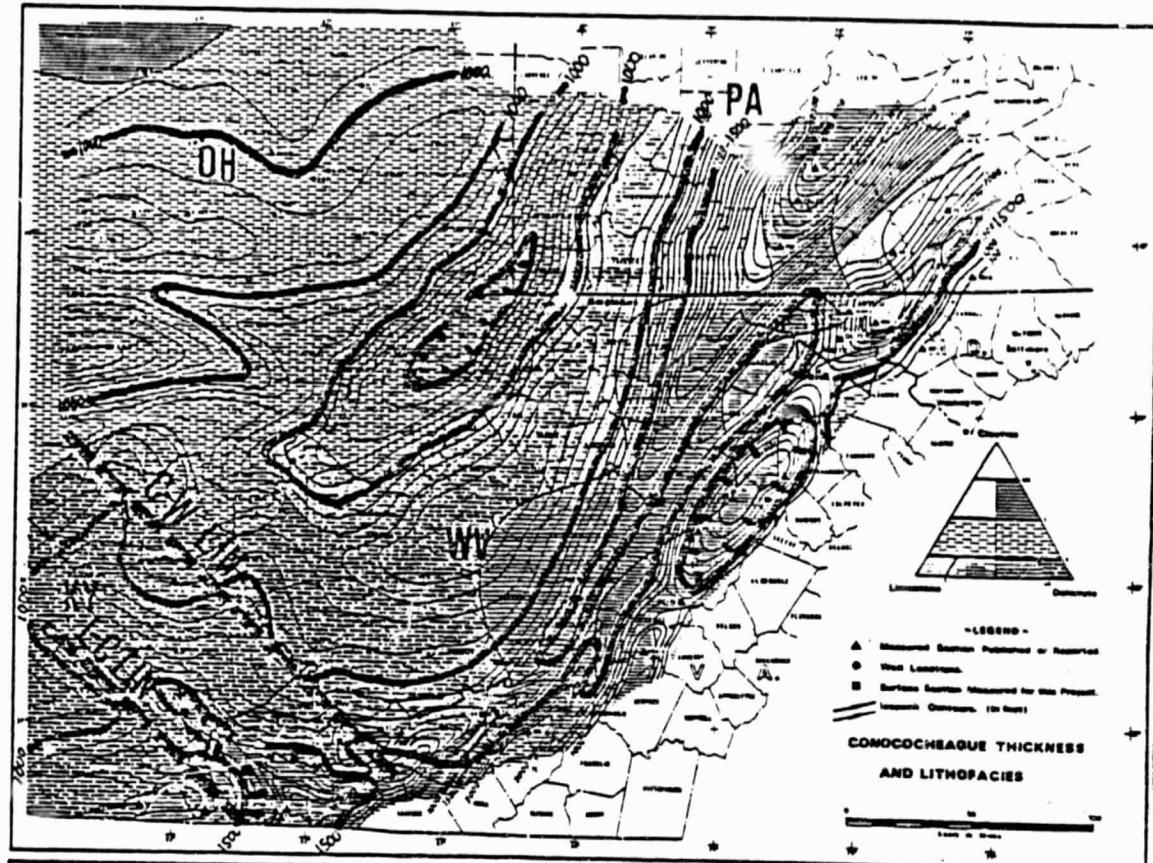
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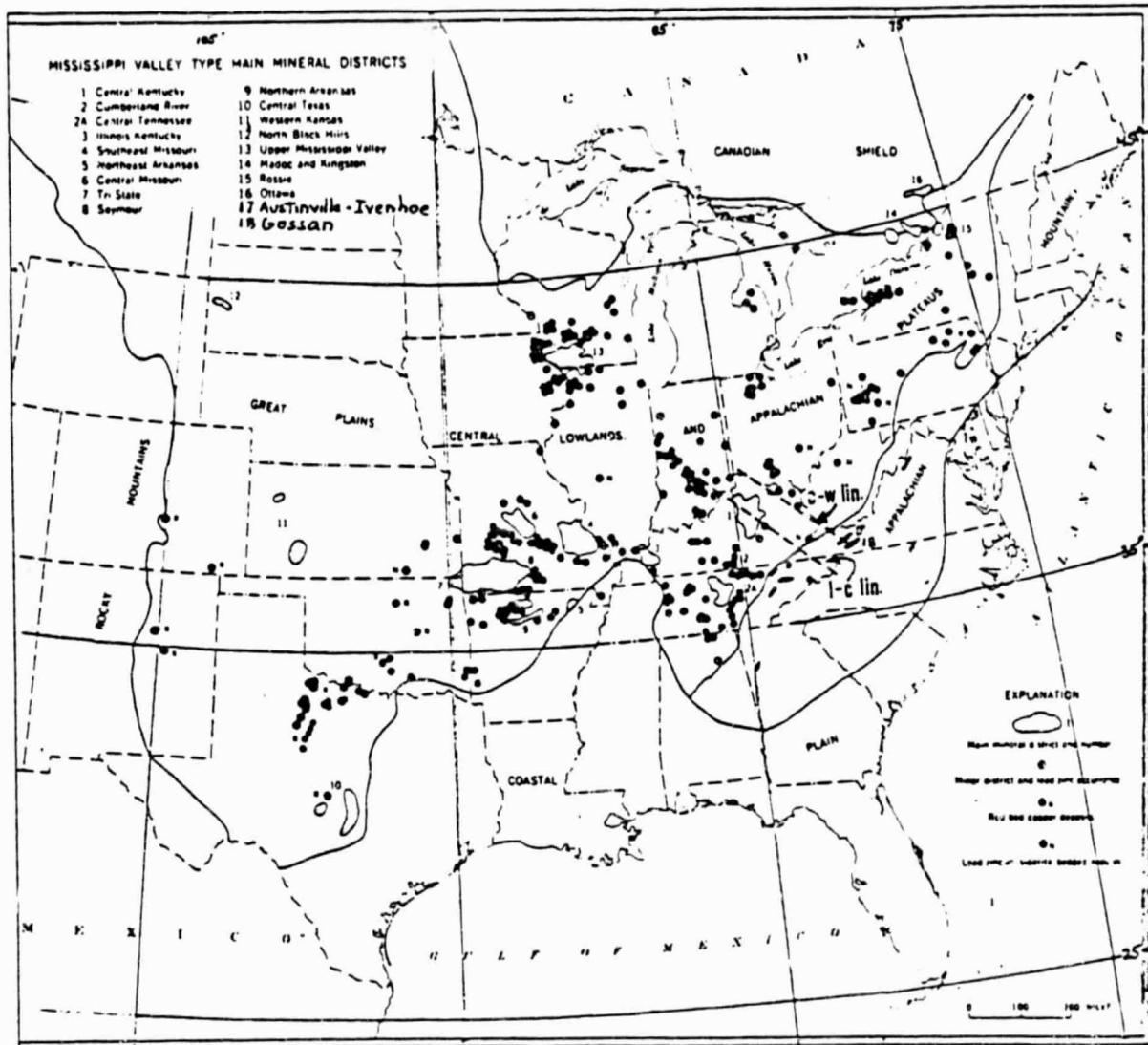
Figure 12
Mississippi Valley Type main mineral deposits, and major
epigenetic, diagenetic, and syngenetic sulfide
deposits in the Central and Eastern United
States. Dashed lines show boundaries of the
proposed crustal block. Modified
from Heyl (1968).
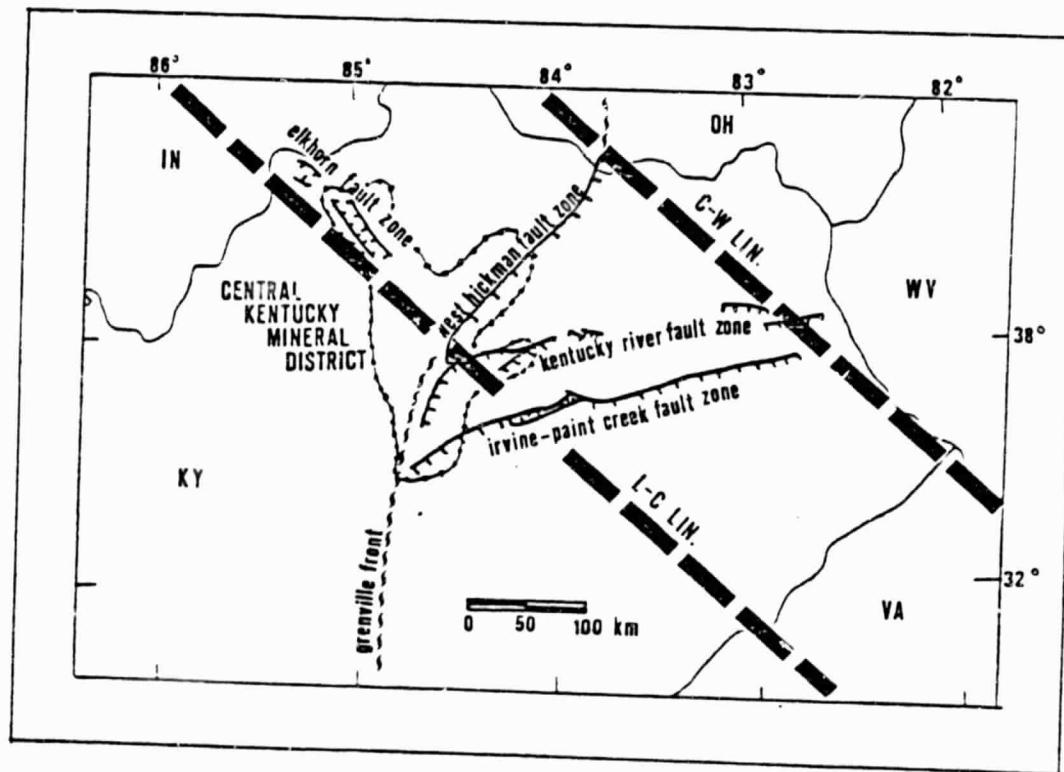
Figure 13
Map showing Central Kentucky Mineral District and associated
faults. Dashed lines show the boundaries of
the proposed crustal block.
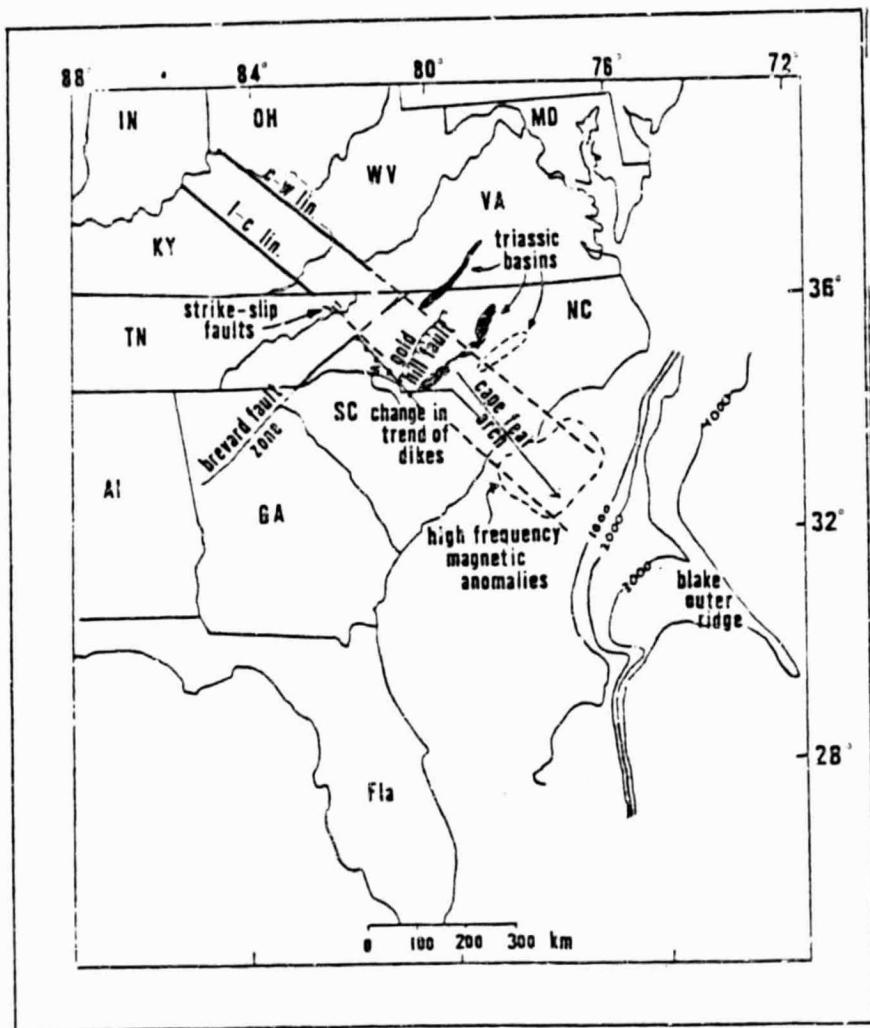
Figure 14
Features used in possible extension of the proposed crustal
block to the southeast. Modified from Barosh (1981).

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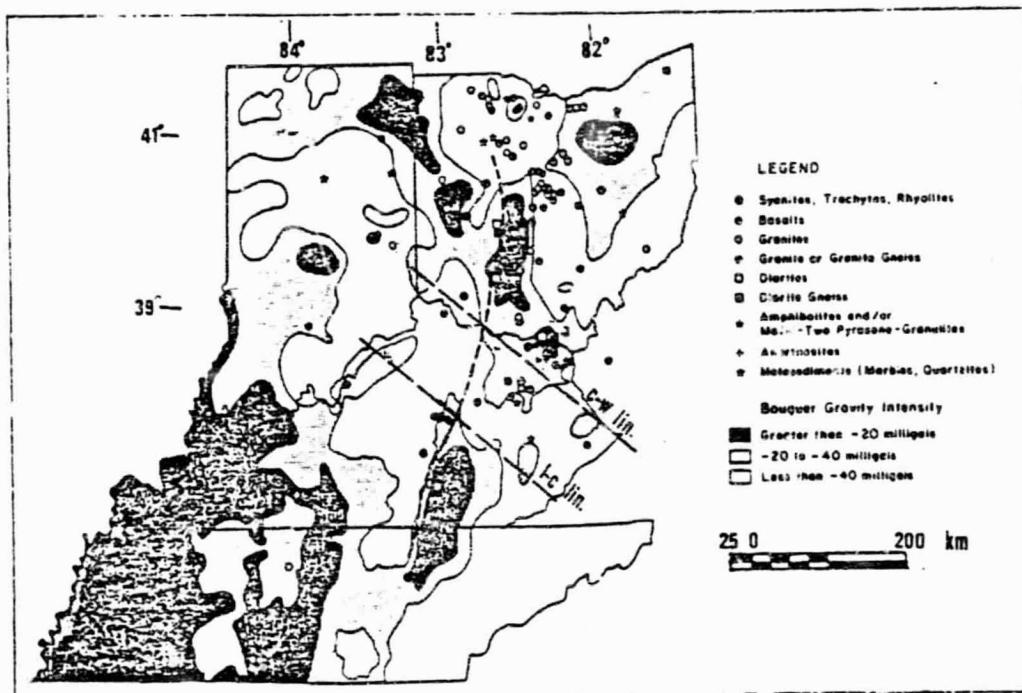
Figure 15
Generalized map showing large scale gravity anomalies and
basement lithologies encountered in wells in the study area.
Long dashed lines show the boundaries of the proposed crustal
block. Short dashed line shows the Grenville Front.
Modified from Keller et al., (1982).
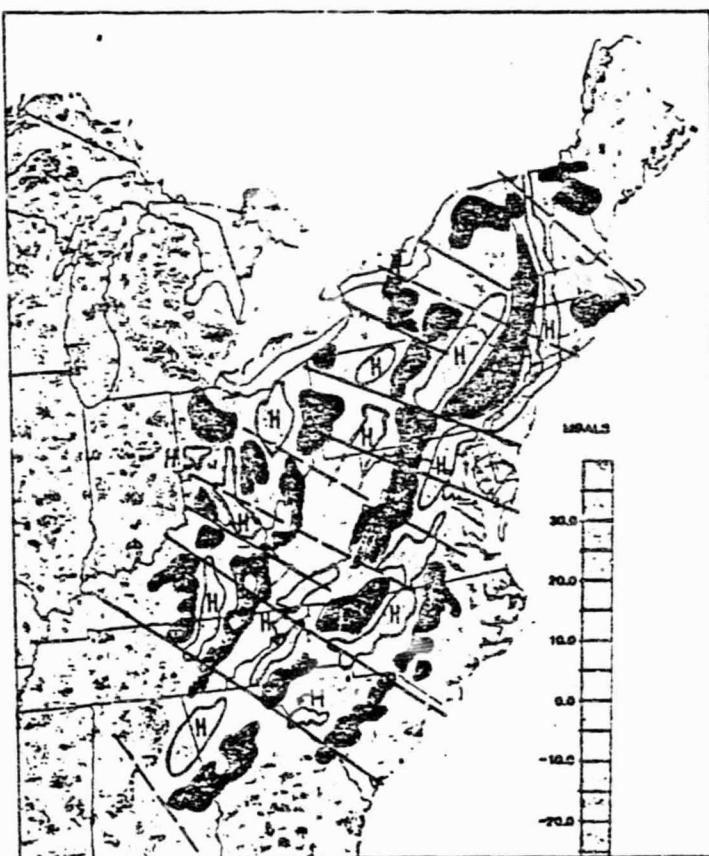
Figure 16
Filtered Bouguer gravity map of eastern United States showing
possible block boundaries. Modified from Kerr (1982).

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